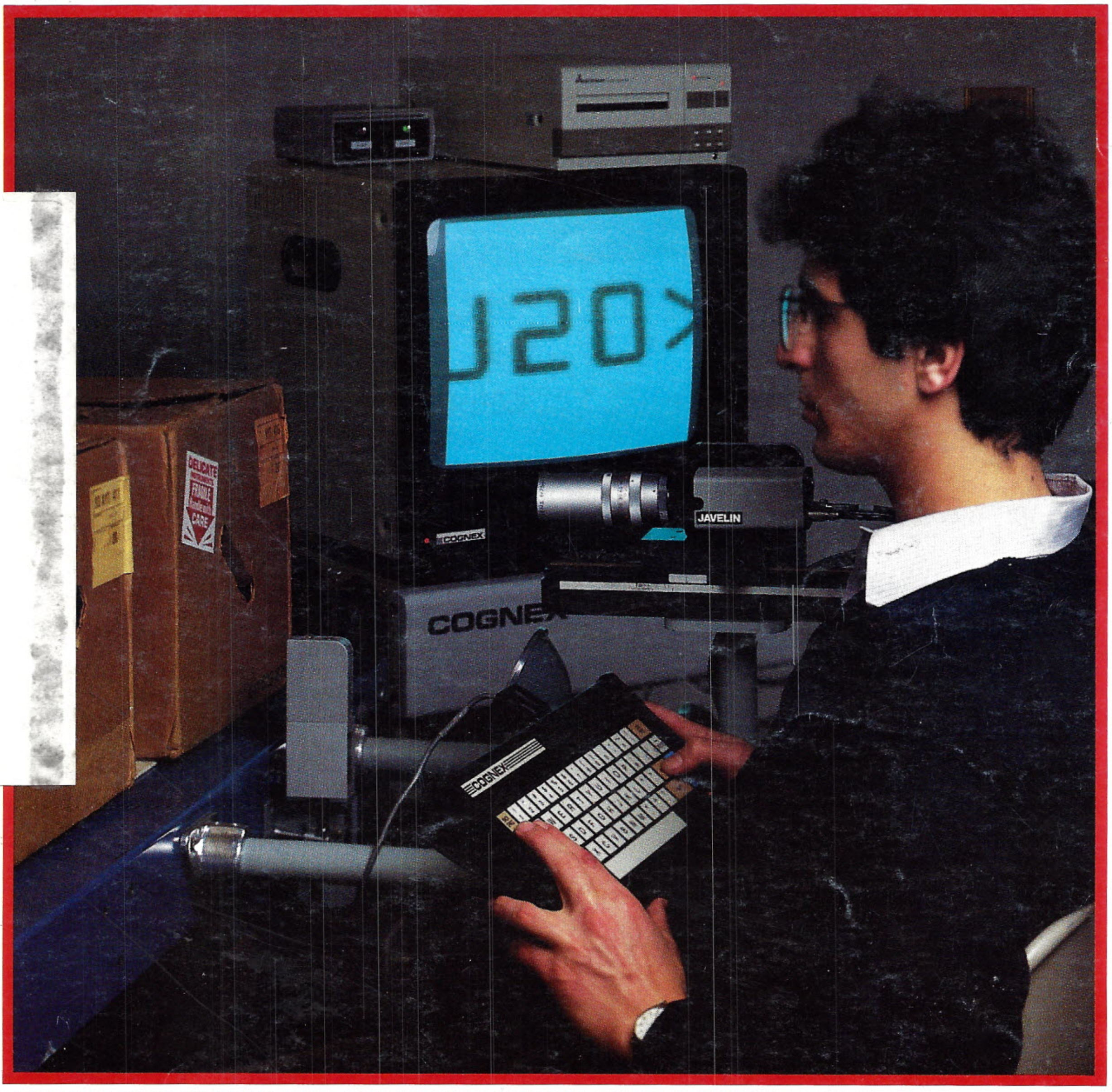
VISION TECHNOLOGY

MARCH 1985 VOL. 7 NO. 3
$3.00 USA/$3.50 CANADA
THE JOURNAL OF INTELLIGENT MACHINES

ROBOTICS AGE™



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Member of Business Publications Audit

ROBOTICS AGE—(ISSN 0197-1905) is published monthly by Robotics Age Inc., Strand Building, 174 Concord Street, Peterborough, NH 03458, phone (603) 924-7136. Address subscriptions, changes of address, USPC Form 3579, and fulfillment questions to *Robotics Age* Subscriptions, 174 Concord Street, Peterborough, NH 03458. Second class postage paid at Peterborough, NH and at additional mailing offices. **POSTMASTER:** Send address changes to ROBOTICS AGE, 174 Concord St., Peterborough, NH 03458.

Subscriptions are $24 for one year (12 issues), $45 for two years (24 issues), $63 for three years (36 issues) in the USA and its possessions. In Canada and Mexico, subscriptions are $28 for one year, $53 for two years, $75 for three years. For other countries, subscriptions are $32 for one year, surface delivery. Air delivery to selected areas at additional charges, rates upon request. Single copy price is $3 in the U.S., $3.50 in Canada and Mexico, $4 in Europe, and $4.50 elsewhere. Foreign subscriptions and single copy sales should be remitted in United States funds drawn on a U.S. bank.

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THE JOURNAL OF INTELLIGENT MACHINES

ROBOTICS AGE™

MARCH 1985 VOL. 7 NO. 3

EDITORIAL

FEATURES

DEPARTMENTS

About the cover: This issue's cover photograph was provided courtesy of Cognex Corporation. It illustrates the use of a Cognex Dataman 1100 machine vision system to read labels on shipping containers in a production environment.

Editorial

BY CARL HELMERS

Vision Systems Are Here

The practical technology of observing scenes and closing system feedback loops is no longer an experiment. There are vision products available ranging from low-cost low-resolution cameras to high-speed high-resolution subsystems with corresponding interfaces. Software varies from simple utility routines to complete object recognition algorithms. This issue samples the technical issues of how vision systems work.

THE WHOLE PICTURE

Robotics Age covers the whole field of intelligent machines and their applications. It covers information about the products, technology, and practices of engineering systems that use modern electronic computer technology interfaced to the real world in real time. The topics range from practical robotic techniques to the artificial intelligence strategies used to automatically plan actions of complicated systems.

Experimentation is where new technology originates; the personal robot of today is such an experiment. The idea of a personal robotics market is inspired by the romance of science fiction, in much the same way that the romance of flying like a bird inspired aviation in the early twentieth century. In some forms it is an engineering educational tool intended for persons wanting to learn about computer control of mechanisms. The new Arctec Gemini product is one example.

As an experimental technology, the personal robotics effort has been likened to the early personal computer field; there are differences, however. Quantum jumps in the microelectronics field enabled the multibillion-dollar personal computer industry to form. Even the personal computer industry would never have happened unless people found a use for the personal computer. The personal computer is inherently useful—for those who need it as a tool of intellectual effort. To date, no one has yet found the usefulness necessary to drive a personal robotics marketplace. As an inspiration to experimentation and research, the personal robot has a place in the technological world of intelligent machines. Significant developments in artificial intelligence research will always be important and reported through these pages.

What we present is a steady evolution of engineering concepts along a broad front of intelligent machine applications in industrial, commercial, and experimental spheres. We combine high-quality technical articles with news and information about the design, systems integration, and application of intelligent machines. During coming months, we'll be emphasizing the practical, industrial, and commercial engineering applications of intelligent machine technology a bit more.

A NEW PUBLISHER AND OTHER CHANGES

This issue represents several changes at *Robotics Age*. For those who watch mastheads of magazines, Christopher Crocker has joined the *Robotics Age* team as Publisher, allowing me to concentrate my efforts on the editorial end of the magazine. Ray Cote has left the company to pursue other interests.

Circle 1

MARCH

5–7 and 26–27 March. Advanced Positioning Technology Seminars. Hauppauge, NY. Contact: Martin Meyers, Seminar Coordinator, Anorad Corporation, 110 Oser Ave., Hauppauge, NY 11788, telephone (516) 231-1990.

Anorad Corporation's series of free seminars is designed to provide engineers, managers, and technical personnel involved in positioning applications with a comprehensive overview of the corporation's latest developments. The focus of the seminars will be positioning equipment—principles of design, CNC and intelligent axis, controller options, and optical accessories. There will also be hands-on demonstrations.

5–7 March. Man-Machine Interface. Beverly Ramada Hotel, Los Angeles, CA. Contact: Continuing Education Institute, 10889 Wilshire Blvd., Los Angeles, CA 90024, telephone (213) 824-9545.

The Man-Machine Interface symposium is directed toward R&D program managers, technically oriented managers, system engineers, and system designers. It will address new tools, guidelines, and methods for the design of the man-machine interface with special emphasis on incorporating human performance requirements into system designs. Also to be discussed are recent and projected developments involving "natural" man-machine control of complex systems.

11–14 March. 1985 National Design Engineering ASME Conference and Short Courses. McCormick Place, Chicago, IL. Contact: Show Manager, National Design Engineering Show, Cahners Exposition Group, 999 Summer St., Stamford, CT 06905, telephone (203) 964-8287.

The computer's future impact on automating the design process and on the creativity of design engineers will be considered in the two keynote addresses opening this conference. There will also be 40 sessions in four areas: Technical Management, CAD/CAM, Materials and Processes, and Electro-Mechanical Systems and Elements. In addition, 19 full-day short courses are scheduled.

11–14 March. 1985 National Plant Engineering & Maintenance Show and Conference. McCormick Place, Chicago, IL. Contact: Show Manager, National Plant Engineering & Maintenance Show, Cahners Exposition Group, 999 Summer St., Stamford, CT 06905, telephone (203) 964-8287.

The show and conference will feature for the first time a New Products Showcase. Exhibitors' products and innovations will be judged in categories.

18–21 March. Westec '85. Los Angeles Convention Center, Los Angeles, CA. Contact: Tom Akas, SME, PO Box 930, Dearborn, MI 48121, telephone (313) 271-0777 or George Mentzer, ASM, Metals Park, OH 44073, telephone (216) 338-5151 ext. 507.

This year's Western Metal & Tool Exposition & Conference will be sponsored by the American Society for Metals, the Society of Manufacturing Engineers, and the American Machine Tool Distributors' Association. Thirty-five technical sessions and workshops will cover such high-tech areas as machine vision, light metals, artificial intelligence, composites, manufacturing in space, lasers, and robotics.

19–20 March. Robotic End Effectors: Design and Applications Seminar. Holiday Inn Livonia-West, Livonia, MI. Contact: John McEachran, Special Programs Department. RI/SME, One SME Drive, PO Box 930, Dearborn, MI 48121, telephone (313) 271-1500, ext. 382.

Calendar: *Continued from p. 3*

This seminar will give comprehensive coverage to robotic end effector design techniques, sensors for tooling, compliant devices, interchangeable end-of-arm tooling devices, multihand tools, and magnets for tooling. A number of case-study presentations will look at robotic end effectors for assembly, material handling, machine loading, metal cutting, and welding robotic systems. An added feature will be end effector vendor tabletop displays.

20 March. The Robotic Assembly Work Cell. Ontario Robotics Centre, Peterborough, Ontario, Canada. Contact: Susan Harvey, Workshop Registrar, Ontario Robotics Centre, 743 Monaghan Rd., Peterborough, Ontario, Canada K9J 5K2, telephone (705) 876-1611 (Peterborough) or (416) 675-4363 (Toronto).

This seminar is designed for companies and individuals seeking a practical introduction to the robotic assembly process.

25–27 March. Applied Robotics for Industry. East Brunswick, NJ. Contact: Mrs. Edith Webb, Registrar, PO Box 964, East Brunswick, NJ 08816-0694, telephone (201) 238-1600 (for registration) or General Information, PO Box H, East Brunswick, NJ 08816-0257, telephone (201) 238-1600.

The purpose of this practical course is to prepare participants to make informed decisions leading to successful robotic applicatons. Emphasis will be placed on understanding robotics technology so potential users can analyze their particular requirements, evaluate robot specifications, deal with vendors, make correct selections, and install a profitable system.

25–28 March. 1985 IEEE International Conference on Robotics and Automation. Marriott Pavilion Hotel, St. Louis, MO. Contact: Robotics, PO Box 639, Silver Springs, MD 20901, telephone (301) 589-8142.

The conference will focus on all aspects of robotics and automation, including robot kinematics, dynamics and control, modeling, simulation, programming languages, CAD/CAM, computer vision and other sensor-based systems, manufacturing technology, and automated inspection. There will also be two tutorial workshops: Special Topics on Robots and Special Computer Architecture for Robotics and Automation.

26–28 March. Vision '85. Cobo Hall, Detroit, MI. Contact: Jeff Burnstein, Robotics Industries Association, PO Box 1366, Dearborn, MI 48121, telephone (313) 271-7800.

Vision '85 will be the first major exhibition of machine vision systems and related equipment ever held. A comprehensive technical conference will accompany the show. Over 75 ex-

Continued on p. 31

Letters

DREAM MACHINE

I am still waiting for the Apple II of the robot world to come through. I want a 68000-based open systems bus architecture with a monitor and keyboard. It should have the capability of allowing independent smart peripherals. It should be able to lift at least 20 lbs. It should have an arm with reasonable placement accuracy and repeatability. It should have the standard Polaroid sonar sensors, heat and motion sensors. It should provide the capability of adding in voice and video recognition boards...So much for my fantasy.

I am very interested in the world's first robot table tennis championship. This of course could lead to countless other possibilities such as a robot tennis championship...And who knows—maybe a robot will eventually win Wimbledon... Just think of it...Mankind might receive two blows together: while one chess-playing computer wins the chess championship another agile robot may beat the world's best tennis player. I mean we could lose in both the brains and brawn category to these machines.

I have spent a lot of time thinking and reviewing vision and recognition literature. I feel that people have been looking at the robot vision problem from an academic, general-purpose viewpoint. The research is aimed at general-purpose solutions which are of neccessity complex and unworkable. My solution is to apply the technology with an appropriate understanding of the task at hand.

Take the example of picking up a table tennis ball in midflight. The general-purpose solution would be to remove the background clutter, adjust the data for the impact of the robot's own movement, then look for a moving white circle. This is a CPU-intensive operation which will work but will need some very good search and match algorithms, along with a fast processor. Now suppose you painted the ball with a special IR reflectant such that if you shine an appropriate IR light and used the matching IR filter in your pickup (camera) then the processing requirements are eased considerably. In fact, with the proper equipment there is no processing required beside the basic triangulation to quickly locate the ball and its trajectory. The system does not have to use IR either. If the organizers permit then a microwave system could be used and a matched strip of aluminum be placed inside the ball. This would permit very accurate measurements and could lead to very good response times for the robot players.

Of course, the strip must be light enough such that it does not affect the trajectory of the ball. Possibly the ball could get an aluminum paint coating of the right wavelength. In general, it is my contention that recognition systems can be broken down into three categories. These categories apply to uni-target systems, i.e. where the system has to recognize and localize one given target only.

1. Those cases where the target is cooperative. By cooperative I mean where the target can be modified to fit the vision system without affecting the performance of the target. In this case, very simple recognition circuitry is needed and the brunt of the processing is used to localize the target. An example is the table tennis ball with IR paint. In this case the vision system should see only the ball and nothing else. So the recognition part is trivial and all that is needed is to locate it via triangulation.

2. Those cases where the target is fixed and cannot be modified to match the vision system. By fixed I mean targets which have fixed shapes but are fully visible and the system has no trouble recognizing the target. The object of the system is to localize the target in space-time. This requires more circuitry than Case 1 as some processing is required before the target is identified. An example would be the case where the table tennis ball cannot be modified and the vision system has to recognize the ball before it can locate it.

3. Those cases where the target is hostile. By hostile I mean where the target is partially visible or different components of the target are visible at any one time. This is the general case and requires a lot of processing before the target is recognized. This case requires a very considerable amount of circuitry to try and match shapes to target. An example would be to try to recognize aircraft.

It is my contention that a lot of vision problems are of Case 1 and do not need expensive recognition and processing. I feel that most systems are targeted for Cases 2 and 3 when in fact their objective is to recognize a Case 1 target. This desire for a general-purpose system independent of the target has bedevilled both industry and academia and much progress in robotics has been slowed because everybody is waiting for a reasonable cost implementation of Cases 2 and 3. Although this objective is laudable it should not cause myopia in industry's eye and prevent the construction of low-cost Case 1 systems.

Rafe Husain
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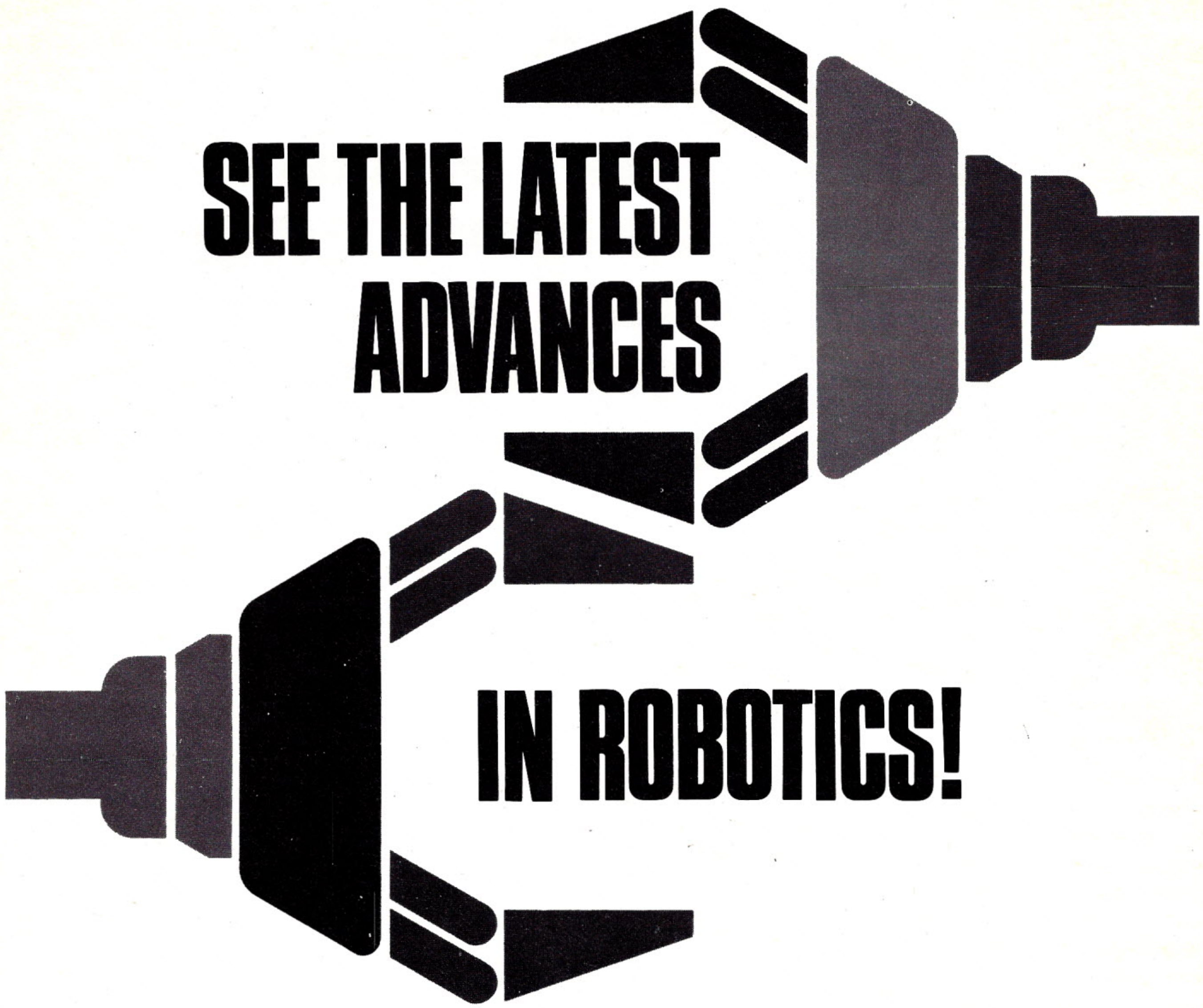

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MINIATURE CCD CAMERAS: A NEW TECHNOLOGY FOR MACHINE VISION

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Today, many robots are being equipped with cameras to recognize objects and patterns as well as to position robot arms. The video cameras used in these machine vision applications require a high-quality image for precise placement and measurement; compactness or miniature size due to space limitations; and long life in difficult operating environments.

To meet these needs, solid-state cameras provide an attractive prospect. One new form of solid-state image sensor is the CCD (charge coupled device) camera. This image sensor provides perfect image geometry with an array of photosensor elements in precise rows horizontally and vertically. The pixel arrangement is predetermined in the semiconductor's layout on a plane of silicon. Thus, the solid-state camera's geometry is much more precise than the older vidicon technologies because pixel scanning is built into the design. In addition, this new Sony CCD camera virtually eliminates the smear phenomenon associated with many earlier solid-state cameras. The new black and white video camera uses a CCD image sensor with associated genlocking circuit. For compactness, its packaging employs a miniature two-sided chip mounting technology.

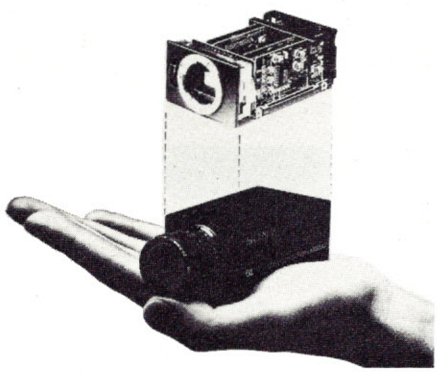

Photo 1. A semiconductor image sensor, such as this Sony CCD camera, can be quite compact. The miniaturized electronics make its size comparable to a human hand. Internal structure is shown by the upper image, taken without its cover.

CAMERA CONSTRUCTION

An internal and external view of the CCD camera can be seen in Photo 1. Note that its solid-state structure contributes to its small size, allowing it to fit in the palm of the hand.

A functional diagram of the camera can be seen in Figure 1. The camera consists of a camera module and genlock unit. The camera module contains both the CCD clock driver and video signal processor. The driver uses CMOS integrated circuits while the video processor, which includes sample and hold for the CCD output, automatic gain control (AGC) and automatic iris control (AIC), employs bipolar integrated circuits. The driver and processor are packaged in a box measuring 1-1/8 by 1-1/16 by 2-7/8 in. and weighing 4.1 oz.

The genlock unit is used to lock the camera clock against an external horizontal drive pulse (ext HD) and an external vertical drive pulse (ext VD) where HD is harmonically related to VD. The unit consists of a phase comparator (PC) which is part of a phase-lock loop made of the VCO and sync generator (SG) in the camera module. Thus the internal HD and CCD scanning clocks are phase locked against the external HD. The external VD determines the timing of the start of frame scanning.

CCD IMAGE SENSOR

The solid-state image sensor is extremely low in geometrical distortion since its pixels are prealigned in the layout design. Previously, solid-state sensors exhibited a tendency to smear when shooting bright

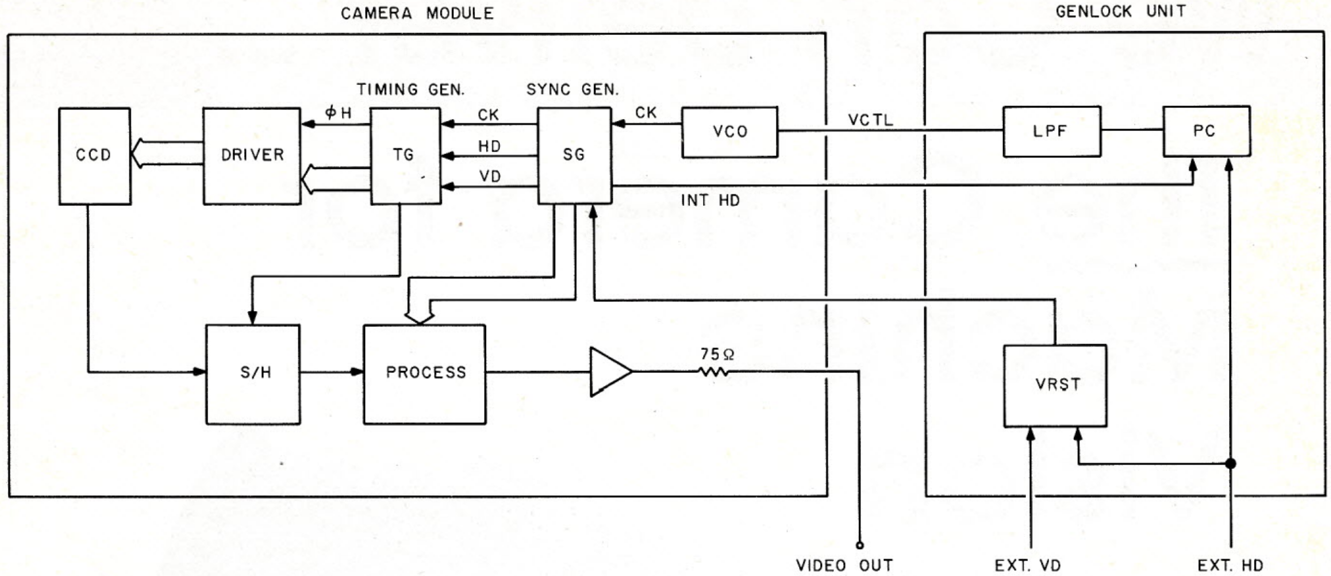

Figure 1. Camera System Diagram. The CCD camera consists of two major modules. The Camera Module contains the CCD image sensor, timing and sync generation circuitry, a CCD sensor output sample/hold circuit and a final output processor to generate a standard video signal. The Genlock Unit contains electronics to phase lock the horizontal and vertical drive of the camera to an external source, such as computer system which must accept images from multiple cameras.

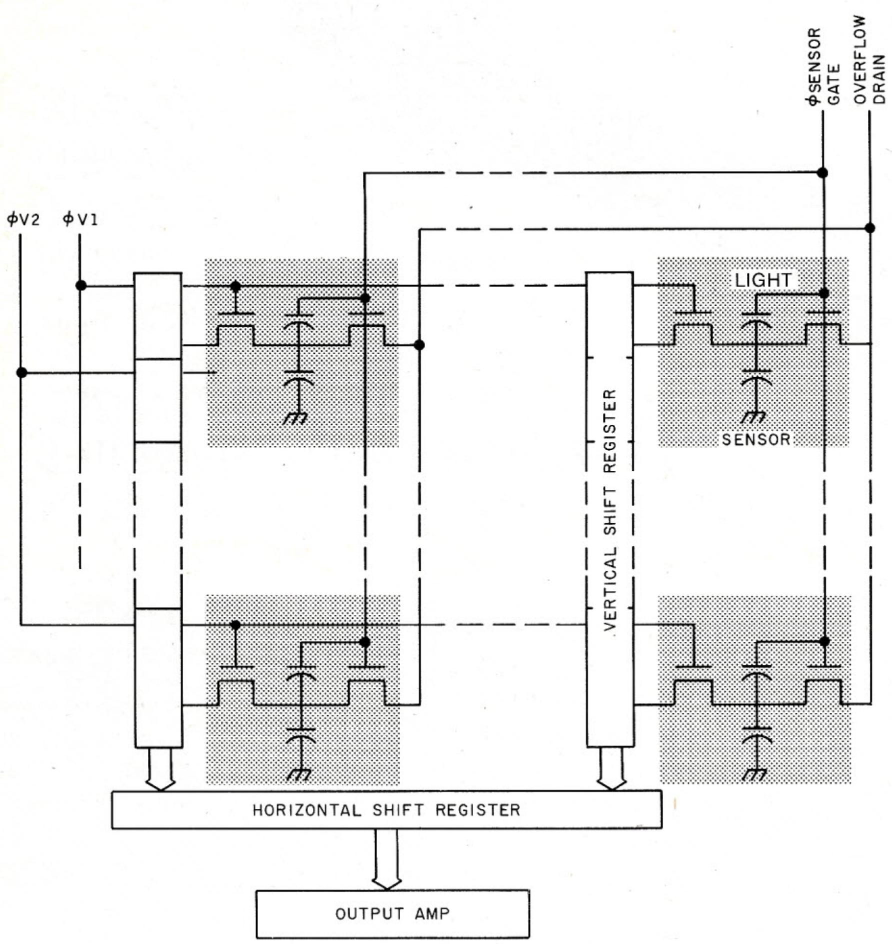

Figure 2. Structure of CCD Image Sensor. This is a schematic representation of the sensor array. At each pixel location, the amount of light present determines a charge value that can be transferred to the element's charge coupled device shift registers. Every 1/30th of a second, the charges present at the entire array of pixel locations are transferred into an array of vertical shift registers. A characteristic of charge coupled device shift registers is that the analog (not digital) amount of charge is transferred from one stage to the next at each clock pulse. At each vertical clock pulse, the output of all the vertical shift registers is transferred into the horizontal shift register. At each horizontal drive clock pulse, one of the horizontal shift register cells is transferred to the output amplifier.

spots. Such smears lessen picture quality and can cause errors in image measurement. ("Smear" should be distinguished from "blooming," which occurs when electrons in the photosensor overflow to the vertical register. Blooming suddenly appears when the light level exceeds a fixed threshold. The length of a vertical bright line caused by blooming is sometimes shorter than the total vertical length of the screen.)

To remove the smear, Sony developed a new interline transfer-type CCD image sensor. (H. Matsumoto et al., "Interline Transfer CCD Imager with MOS Photosensor Using High Resistive Substrate," *The Journal of the Institute of Television Engineers of Japan*. Vol. 37, No. 11, 1983). The structure of this CCD image sensor is shown schematically in Figure 2. The sensitivity spectrum of the CCD camera, which extends over a visible region to a near infrared region, is plotted in Figure 3.

In the inter-transfer-type CCD, the electrons generated in the photosensor are fed into the vertical shift register simultaneously every 1/30 second. When infrared light enters the CCD image sensor, it passes through the depletion layer and reaches the neutral region underneath. Electrons are generated in the neutral region and diffuse into the vertical shift register.

To protect the imager from smear, the new CCD sensor by Sony uses a highly resistive substrate which increases the depth of the depletion layer and thereby makes it more difficult for infrared light to reach the neutral region. In addition, the

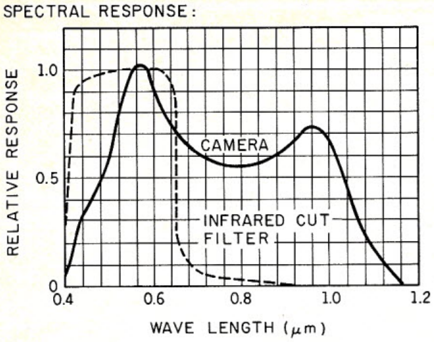

Figure 3. Sensitivity Spectrum. The relative response of the CCD Image Sensor to light versus wavelength is plotted in this diagram. The dotted line shows a response curve of an infrared cut filter which is optionally used to lessen the effect of the peak at the lower end of the sensitivity spectrum.

vertical register is so structured that it is surrounded by a p-type well. As a result, smear has decreased to one-tenth of that for structures which do not use a highly resistive substrate and p-type well.

In the interline transfer-type CCD imager, all of the electrons in the photosensor may not be transferred to the vertical register. The incomplete transfer of electrons can cause image lag. The problem may be more serious when a photodiode type sensor is used. The current CCD imager is an MOS type sensor having a thin polysilicon electrode. This electrode enables a complete transfer of electrons from the photosensor to the vertical register. Thus, the problem of image lag has been eliminated.

EXTERNAL GENLOCKING

Three harmonically related clock pulses are needed to operate a CCD camera: a CCD scanning clock (Φ_H), horizontal drive pulse, and vertical drive pulse. The frequencies chosen for the current CCD imager are:

CCD scanning clock:
$f_{\Phi H} = 7.15909$ MHz
horizontal drive pulse: $f_{HD} = f_{\Phi H}/455$
vertical drive pulse: $f_{VD} = 2f_{HD}/525$

Therefore, three external pulses corresponding to Φ_H, HD and VD are required for genlocking. Among the three, the frequency of Φ_H is as high as 7 MHz. Since the transmission of the Φ_H is not desirable from a system point of view, genlocking has been worked out with only HD and VD. The internal horizontal drive is generated by counting down the Φ_H pulses.

The phase lock loop consists of a sync generator and a voltage controlled oscillator (VCO) in the camera module, and a loop filter (LPF) and a phase comparator in the genlock unit. The signal CK, shown in Figure 1, is the output of the voltage controlled oscillator and and has a frequency of 14.31818 MHz. The CK signal is fed to the sync generator where it is counted down to provide the internal HD. Next, the internal HD signal is fed to the phase comparator where the phase difference between the internal HD and external HD signals generates a control voltage (VCTL). When the phase lock loop is stable—i.e. "genlocked"—the f_{CK} can be represented as:

$$f_{CK} = 2f_{\Phi H} = 910\ f_{HD}$$

The voltage controlled oscillator is tuned by means of an LC (inductance-capacitance) circuit and can adjust its frequency within a much wider range than a crystal oscillator (see Figure 4). The lock-in range for the phase lock loop is ± 1 percent. For comparison, the lock-in range of a crystal oscillator is typically ± 0.003 percent. It should be noted that the external VD is used to form an initializing pulse which determines the timing of the start of the frames.

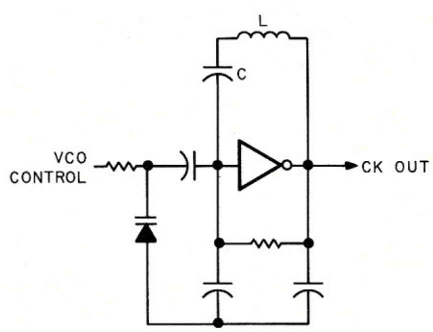

Figure 4. Voltage Controlled Oscillator. A wide frequency range (± 1 percent) is achieved with this LC tuned voltage controlled oscillator used as part of the camera's "genlock" technique to phase lock scanning with an external horizontal drive source. If the camera were to use internally generated control timing, a crystal oscillator would have been appropriate instead.

MINIATURIZATION

Because CCD cameras are becoming an integral part of machine vision systems, and frequently must be mounted on the moving parts of robots, size and weight become important considerations. To reduce size and weight, Sony has implemented the following design strategies:

- Dense packaging. Use of high density two-sided chip mounted PC boards. These can be seen in Photo 1's top image of the camera's internal parts.
- Radiation fin cooling. To cool the densely packed camera, a radiation fin is used to dissipate heat to the outside of the camera module. This method of cooling was selected because it was felt that convection cooling would not work efficiently in so densely packed a device. Radiation fins are also mounted in the cover, which radiates the heat generated in the central region of the camera module.
- Miniature lenses. Sony developed mini bayonet mount lenses for use with the CCD camera. An F 1.4 f 16 mm lens weighs only an ounce. A corresponding lens would be several times heavier. There is also a C mount adaptor to accommodate C mount lenses.

CAMERA APPLICATION SYSTEM DESIGN CONSIDERATIONS

The CCD camera module's performance appears in the specifications listed here. Applications suitable for this camera are many. Of particular interest in the robotics field is the precise image geometry achieved through its solid state design. Variations from one camera to another are minimized and translation of image information to real-world geometry is made more reliable than in older vidicon technology.

There are several considerations to keep in mind when interfacing a CCD camera with a video computer system. For one, the CCD camera can be either a slave or a master of the computer. When the CCD acts as master, the clock in the camera dictates the clocking of the computer. Generally, the computer separates the sync pulses from the video composite signal generated in the camera. But when the camera acts as slave and the computer as master, the clock in the computer dictates the clocking of the camera through a genlock unit.

The advantage in the camera as master is that cameras of different designs can be interfaced to the same system as long as the cameras conform to RS-170 standard. However, only one camera at a time can be linked to the computer. When the camera is a slave using the genlock technique, multiple cameras can be interfaced to the same computer. This is a significant

benefit for machine vision systems that must quickly inspect complex surfaces such as interior car panels and therefore need multiple eyes to keep pace with production line runs.

INTERLACE/NONINTERLACE

The design engineer must also consider whether he wants to use the camera in an interlaced mode or a noninterlaced mode. The CCD camera is designed to generate a signal conforming to the RS-170 standard. This means the signal is interlaced with two fields, forming one frame. There are 525 horizontal scanning lines within a frame. The frame repeats at a rate of 30 frames per second. The advantage of the interlaced mode is that the vertical resolution is twice as much as that of the noninterlaced mode. In the noninterlaced mode, there are typically 262 horizontal lines within one frame. The frame repeats at a rate of 60 frames per second. The advantage of noninterlacing is that images are supplied twice as fast as with the interlace mode.

SPECIFICATIONS

Optical system:	Special mini bayonet/C mount with adaptor Flange back length: 8.5 mm (in air) Lens filter: 25.5s
Scanning system:	525 lines, 59.940 fields/sec, 2:1 Interlace
Video output:	1.0 V p-p sync negative, 75 ohms
Horizontal resolution:	280 TV lines
Vertical resolution:	350 TV lines
Sensitivity:	400 luxes, F4 (3200° K, with infrared cut filter)
Minimum illumination:	3 luxes, F1.4 (without infrared cut filter)
S/N ratio:	more than 46 db (AGC off; 0 db)
Power requirements:	12 VDC to power unit, 24V/9.5V/5V to camera module
Power consumption:	2.3 W (Camera module only), 2.9 W (Camera module + Power unit), 3.0 W (Camera module + Power unit + Auto iris lens)
Weight:	Camera module: 115 g Power unit: 100 g Standard lens: 38 g Auto iris lens: 50 g, 62 g (with cable)
Storage temperature:	−30°C to +60°C
Operating temperature:	0°C to 40°C
Vibration resistance:	7 G (11 Hz to 200 Hz)
Shock resistance:	70 G
MTBF:	3000 hours (30000 hours in the limited condition)
Product life:	more than 12000 hours
Power voltage tolerance:	Power Unit 12V: ±10% Camera Module 24V: ±0.8V 9.5V: $^{+0.3V}_{-0.2V}$ 5V: $^{+0.3V}_{-0.2V}$
Storage moisture:	25% to 90%
Operating moisture:	30% to 70%

AGC/NO AGC

In applications where the video output is the measure of the light intensity, the automatic gain control (AGC) should be disconnected. When it is disabled under certain light conditions, the camera may present images with higher contrast.

GAMMA CORRECTION/ NO GAMMA CORRECTION

The CCD camera for use in video application generally has a gamma correction circuit which can be expressed as $y = x^{0.45}$ where y is the video output level and x is light intensity. This exponential nonlinearity built into the camera is designed to compensate for the nonlinearity that exists in cathode ray tubes used for display. In machine vision applications the designer might choose to disconnect the gamma correction. This can increase the contrast between the dark image and the bright image. When the designer is using gray scale

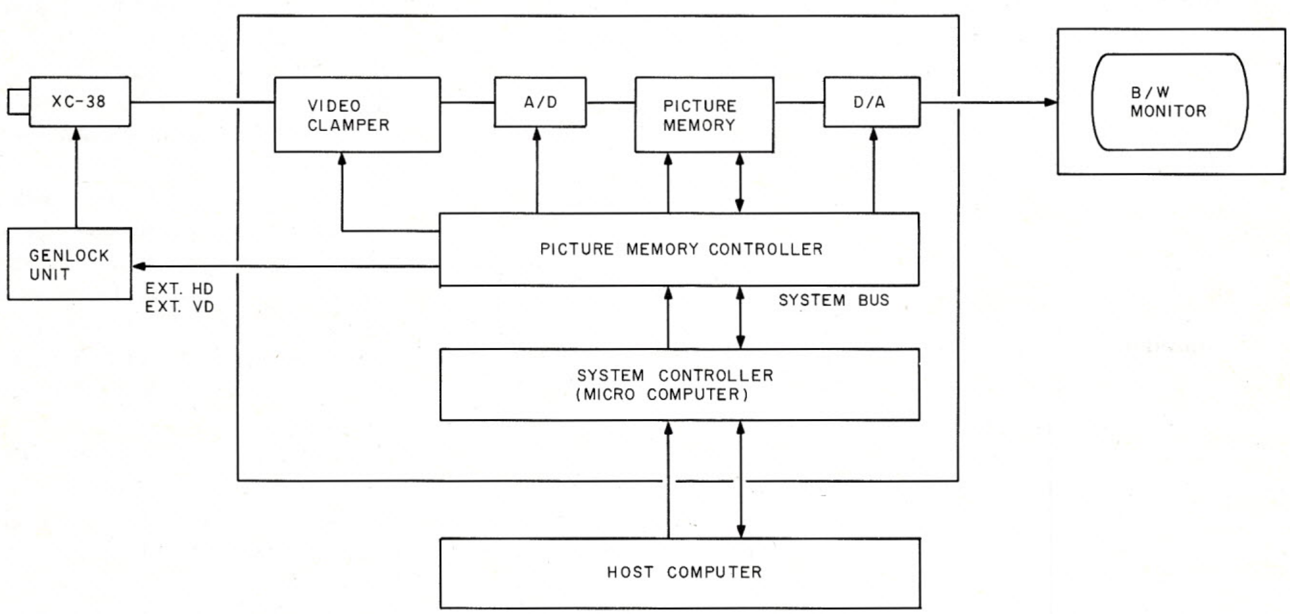

Figure 5. Typical Image Analysis System. The CCD Camera in a typical use feeds an image analysis system such as this. The system features a local controller and picture memory to store and analyze images. The hardware of the "picture memory controller" in this diagram is often provided on a plug in board for one of the standard computer industry busses such as the Std Bus, DEC Q-Bus, IBM PC-bus, or the S-100 bus. A local system controller function can then be provided by a standard microcomputer that often communicates with a host computer for an entire automation application.

digitizing, a linear characteristic is more readily handled than a nonlinear characteristic.

Although the Sony CCD camera module described here has both automatic gain control and gamma correction and is designed as a slave to the computer operating in the interlaced mode, it can be modified easily to offer all the options previously discussed.

IMAGE MEASUREMENT SYSTEM

A block diagram showing the CCD camera as an input device for an image measurement system is shown in Figure 5. Here, a picture memory controller generates a master clock, external HD and external VD which the genlock unit uses to phase lock the CCD camera. The video signal from the camera is digitized and stored in the picture memory, which acts also as a buffer memory and a refresh memory. The digital video signal is fed through the system controller to the host computer. A local display of processed data is produced from the digitized signal and fed through display conversion circuitry to a B/W monitor for display.

SUMMARY

The design of the new Sony CCD camera discussed was intended to satisfy the needs of machine vision applications. In the CCD image sensor, the vertical shift register, highly resistive substrate and p-well structure combine to reduce smear to one-tenth of previous CCD camera designs. The genlocking unit has been designed with an inductance capacitance oscillator which provides for a locking range of ± 1 percent. For miniaturization, the CCD camera's design has extensively employed low-power integrated circuits and two-sided chip mounting techniques. To dissipate heat, radiation fins were employed. Finally, two miniature lenses were designed to provide extra light lenses.

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VISION AND THE COMPUTER: AN OVERVIEW

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Giving the computer the gift of sight can open exciting new worlds of man-machine interaction. The ability to see allows the machine to make decisions based upon the presentation of visual imagery, a task often taken for granted by humans. Furthermore, the computer can act as a tool for the enhancement, restoration, and storage of image scenes for human interpretation. Indeed, the computer's capacity to see represents a major step in the evolution of machine intelligence.

Digital image processing, where image information is processed digitally rather than by other means such as optics or analog electronic circuits, found its first major use in the United States space program. Space exploration programs used digital techniques for image archiving and processing as far back as the early 1960s (see *References* 2,4). Mainframe computers were used for the image processing computations while special-purpose electronics provided the storage and display of the digital image upon a television monitor. Although the techniques for processing digital image data were based on well-known discrete-time mathematics, it wasn't until this time that the need and the electronic technology for digital image storage and display came of age.

Commercial digital image processing systems began appearing on the market in the mid-seventies. These machines provided the necessary hardware for capturing images from standard television signals as well as storing and displaying them. Software to carry out many common image processing functions provided digital image processing capability to the industrial user. Today, with the advent of inexpensive, high speed analog-to-digital converters and cheaper, denser semiconductor memory devices, the digitization, storage, and display of television video images are now possible at prices unheard of a few short years ago.

Today, the microcomputer can bring image processing right into many application environments. Although slower than some special-purpose image processing machines, microcomputer-based systems can provide valuable capability to the low-level user. Any microcomputer can take the form of a complete digital image processing workstation providing image digitization, storage, display, and processing.

This article gives an overview of the typical hardware and software required to perform digital image processing with low-level microcomputer implementation kept in mind.

HARDWARE FOR IMAGE CAPTURE, STORAGE AND DISPLAY

The typical digital image processing system works with standard television format signals as its input and output. So, before a microcomputer can do any image processing, the means to capture, store, and display an image frame must be provided. Further, an appropriate interface to allow computer access to the image storage memory must be available. These bare minimum functions must exist in peripheral hardware to support a computer in its quest to do image processing. Additional hardware can then be added to enhance the speed of certain image processing tasks.

Let's start by discussing the peripheral hardware necessary for a microcomputer to capture, store, and display a single frame of video from a live video source for subsequent processing. The monochrome video signal format used in the United States is the RS-170 standard used for black and white television transmission. This standard is a subset of the National Television Systems Committee (NTSC) color specification containing only monochrome video information. Image processors typically use this signal format for black-and-white work. When color processing is involved, three RS-170 signals are often used to carry the red, green, and blue color information.

The RS-170 standard defines the video composite signal that carries the visual and synchronizing information necessary to reconstruct a transmitted video image. Under this format, the video image frame is defined as containing 525 lines in a 4:3 (horizontal to vertical) aspect ratio. A new frame is transmitted every 1/30 of a second in an interlaced scan pattern. Interlaced scan means that first a field of 262.5 lines is transmitted covering the entire image frame followed by a second field of 262.5 lines interleaved between the lines of the first field.

Working within the limits of the RS-170 signal format, a maximum of 525 lines can be contained in the ultimately digitized im-

age. Often image processing systems will digitize to a vertical resolution of either 256 lines (single field) or 512 lines (full frame) because of the even binary qualities of these numbers.

The RS-170 signal has an inherent bandwidth limit that provides for no more than about 400 or 500 pixels of horizontal resolution. Additionally, each pixel carries a brightness resolution of between 100 to 200 levels spanning the range of grays from black to white.

As a result, digitizing a video line to 512 pixels with a brightness resolution of eight bits per pixel will fully capture the information contained in the RS-170 signal line. Many systems, however, digitize to a horizontal resolution of 256 pixels with either six, seven, or eight bits of brightness resolution and maintain respectable image quality. The images seen in the photos accompanying this article all consist of 256 lines by 256 pixels by 7 bits per pixel.

In order to discuss the mechanics of the hardware involved in capturing a video image we will set the requirements of the system to capture, store, and display an image of size 256 lines by 256 pixels. Each pixel will be quantized to eight bits, or 256 gray levels. Furthermore, the hardware will support access to the image memory by the host microcomputer for image-processing tasks.

The image processor's front-end hardware must take in RS-170 video, massage it with various analog preprocessing circuitry, and convert it to a stream of digital values using a high-speed, "flash," analog-to-digital (A/D) converter. The input analog functions consist of a preamplifier to buffer the signal from the transmission line, a black level clamp to reference the AC coupled video to a known DC voltage level and a sync separator to recover the synchronizing information for system timing and control. The A/D converter takes this analog voltage waveform and converts it to a stream of 8-bit pixels for storage in the image memory.

The image processor's back end must accept pixel data from the image memory, convert it to an analog signal using a high-speed digital-to-analog (D/A) converter, and process it through an output amplifier. The output amplifier serves to mix back in synchronizing information as well as to buffer the outgoing signal. The resulting RS-170 video can then be fed to a standard video monitor for display. Figure 1 illustrates the front-end and back-end analog processor hardware needed by a digital image processing system.

Between the front-end and back-end analog processing sits the most essential portion of the image processor, the image memory. It is here that our digital image sits for processing by the host microcomputer. In addition, the image memory must accept incoming video data from the A/D converter for storage and provide outgoing video data to the D/A converter for display. Of course, a port into the memory for microcomputer access must be provided.

The design of this memory array involves a few tricks in order to handle the requirements of this high-speed data flow. The image memory is an array of semiconductor memory organized to satisfy special timing constraints. Let's review the requirements for a 256 line by 256 pixel by 8 bit per pixel system. Our source video is streaming through the A/D converter and being presented to the memory in a digital form at the rate of 5 MHz, or 200 ns per pixel. This rate is defined by the RS-170 specification. The video line has a duration of about 63 μs, of which 53 μs contain the active visual portion of the line and 10 μs contain the line synchronization information. Dividing the 53 μs time by 256 pixels yields a pixel time of 207 ns (200 ns for our purposes here.)

The display monitor also requires a video output of a pixel's data every 200 ns. The microprocessor wants fast random access to the image memory for the image processing operations invoked by the operator. Although these requirements may seem stiff, there are ways to satisfy them all with an appropriate design.

Typically, dynamic RAM chips, rather than static RAMs, are used for the image memory because of their high density and low power requirements. Also, because of the periodic nature of the video scanning process, the dynamic RAM array is refreshed as an inherent feature of the se-

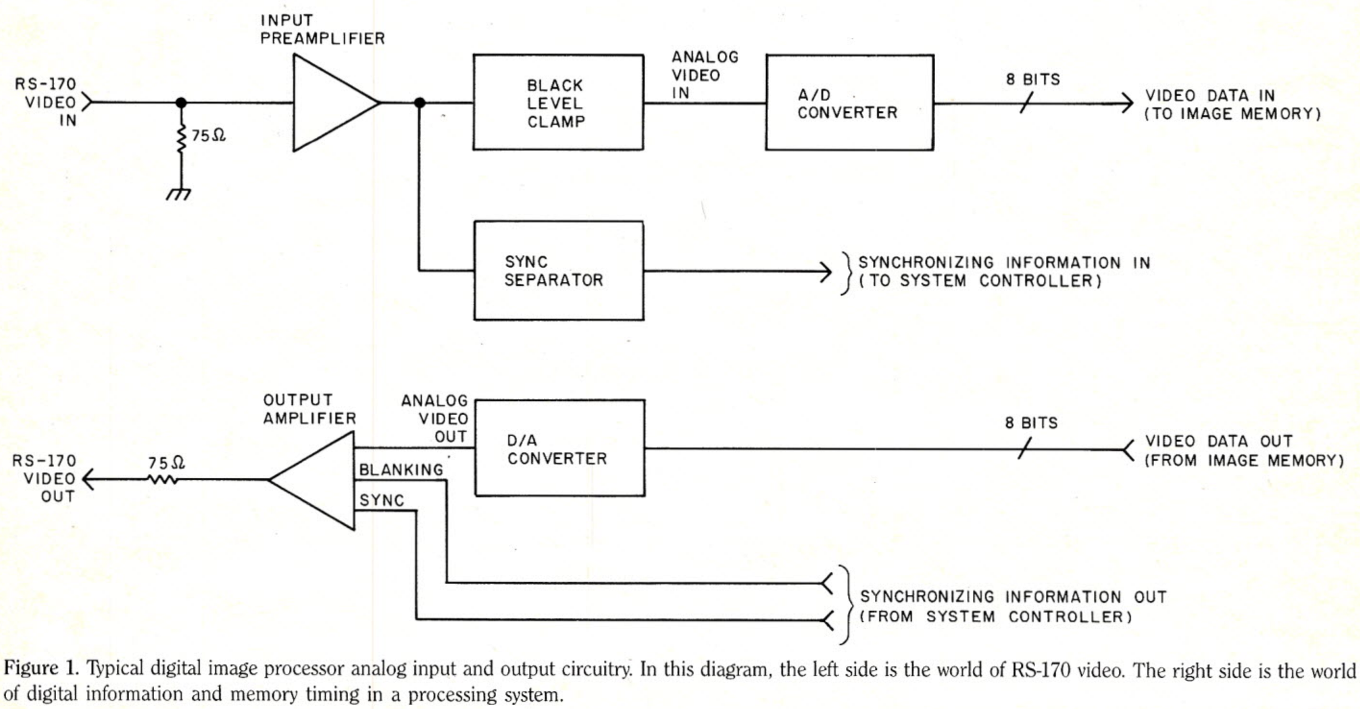


Figure 1. Typical digital image processor analog input and output circuitry. In this diagram, the left side is the world of RS-170 video. The right side is the world of digital information and memory timing in a processing system.

quential and repetitive timing of the system. As static RAM technology improves, however, use of these devices may look more attractive than dynamic RAMs in the future.

A 256 line by 256 pixel by 8 bits per pixel system requires 64 Kbytes of image storage memory. On first inspection, it seems that eight 64 K RAM chips would satisfy the storage requirement, and indeed they do. Looking at the timing requirements, however, we must write incoming pixel data and read outgoing pixel data, two memory cycles, every 200 ns. Furthermore, we need to give the microcomputer access to the image memory without interfering with the capture or display processes. Currently available dynamic RAMs have an average cycle time on the order of 200 ns to 400 ns; we will assume the worse case, 400 ns, for this discussion. In order to work with available dynamic RAM chips, we must use a memory architecture employing pixel buffering and wide data width in and out of the array.

The problem may be solved by using 16 K×4-bit chips. With eight of these chips, 64 Kbytes, we obtain the necessary storage space and have a data width of 32 bits in and out of the array (see Figure 2). The 32 bits represent four 8-bit pixels, so by buffering four pixels from the incoming video we must perform a write cycle only every 800 ns. Likewise, by buffering four outgoing pixels from the image memory, a read cycle need be executed only every 800 ns. By using the read-modify-write cycle supported by dynamic RAMs, we can actually read the four outgoing pixels and write the four incoming pixels all in the same cycle. With a basic dynamic RAM cycle time of 400 ns, we have time for an additional 400 ns read or write cycle every four-pixel time period. This cycle, or course, is used as an external access to the array by the host microcomputer for processing. Figure 3 illustrates this basic memory cycle timing.

We have just described the basic configuration for a 256 line by 256 pixel by 8 bit per pixel digital image processing peripheral. Image capture, storage, and display are handled autonomously and in synchronism with the input video signal. The host microcomputer is allowed transparent access to the image memory every 800 ns, which typically will not bog down the microcomputer in its input/output operations.

The extrapolation to a 512 line by 512 pixel by 8 bit per pixel system is straightforward and can be described in two simple steps. First, the memory array must be quadrupled to 256 Kbytes. Second, the pixel buffering in and out of the array must be increased to eight pixels. These two requirements maintain the timing of the original design and satisfy the increased pixel bandwidth.

COMMON PROCESSING OPERATIONS

Processing of digital image data arrays may occur through either hardware or software implementations. Often hardware means are used when large numbers of images are to be processed repetitively by a particular algorithm. Hardware methods are almost always considerably faster than software methods. The tradeoff is that hardware implementations are usually considerably more expensive than software and, hence, are usually reserved for special-purpose applications. Also, a hardware design has

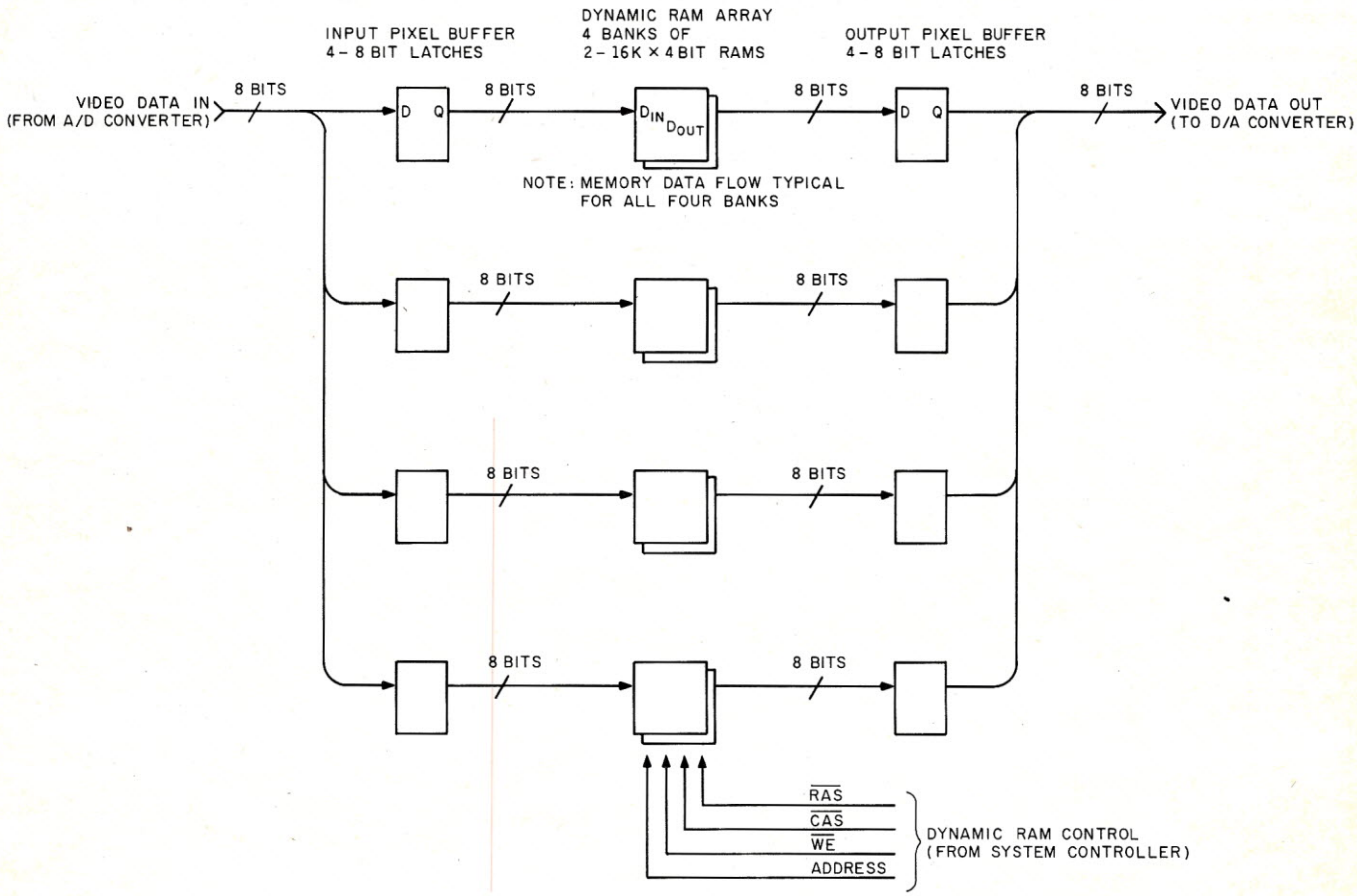


Figure 2. A 256 line by 256 pixel by 8 bit per pixel image memory architecture can be built around eight dynamic random access memory chips each with 16K by 4-bit organization (64K bits total per chip.) This diagram shows the data flow architecture which uses an input 4-pixel buffer to match the slower speed of memory chips to the higher speed of video information.

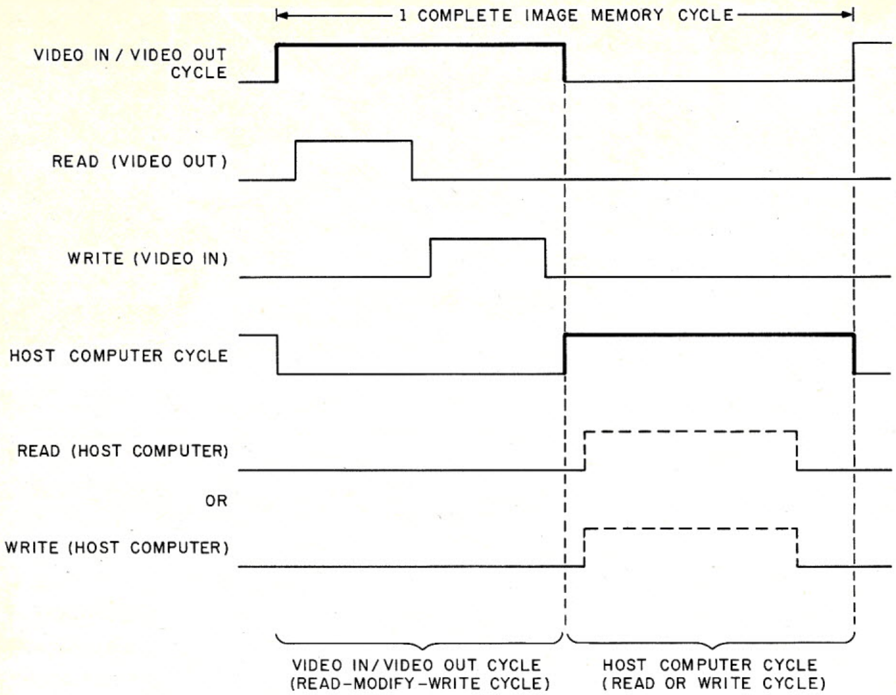


Figure 3. Basic memory cycle timing for a typical image processing system. Alternate phases of the memory cycle allow image memory access by the host computer and the video image input/output conversion process. The video phase of the cycle always performs a read and a write access to the dynamic RAM image array. The computer phase of a typical system has either a read or a write access. This timing method assures that the image as seen on the output monitor or as captured from the video source is never subject to dropouts or glitches due to computer access.

none of the flexibility inherent in software. In the typical digital image processing system, only certain simple processing operations are contained in hardware, with more complex processing limited to software implementation.

Image processing operations can be broken into several classes from which three broad categories are defined: image enhancement, image analysis, and image coding. Each group deals with a particular set of operations used to perform a variety of related functions. Image enhancement operations serve to improve an image's quality, based on the desires or requirements of the user. Image analysis operations, on the other hand, produce information about an image. For instance, a statistical breakdown of the qualities of an image may be generated. Image coding operations are the group of functions used to reduce an image in data size. These operations are often used when an image is to be stored or transmitted in order to reduce storage space or transmission bandwidth.

For the purposes of this article we will primarily discuss enhancement operations, because of their popularity and widespread use. One important image analysis tool, the image histogram, will also be covered.

Image enchancement operations can be broken into two categories: *subjective*

enhancement and *objective enhancement*. Before enhancing an image, the question to ask is: are we enhancing the image for an apparent increased quality (subjective) or correcting it for some known degradation (objective)? In the first case, the attempt is made to derive more visual knowledge from the image as it stands, and the operations are applied at the viewer's discretion.

Objective enhancement attempts to correct some known degradation that the image has encountered and hence does not necessarily strive for a more appealing image. For instance, if the original image was of low contrast, then it may very well be the goal of an objective enhancement to recover the image as it originally existed—low contrast. The following operations may be applied to either subjective or objective enhancement without distinction other than to its application.

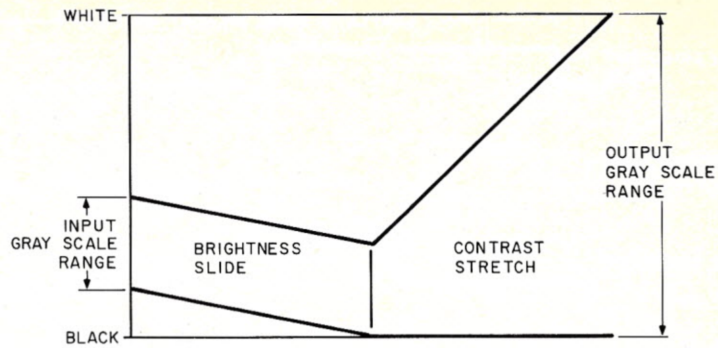


Figure 4. The contrast and brighness enhancement process. This highly symbolic diagram represents the possible pixel values by its vertical dimension and the process applied as transition from left to right. The actual changes per pixel are accomplished by mathematical calculations. Going from left to right, we slide the brightness down to the point where the lowest brightness in the actual image corresponds to zero (total black). Then we multiply by an appropriate scale factor so that the brightest pixel values (white) correspond to the greatest integer in the range.

Contrast and brightness enhancement: The most basic operation applied to any digital image is that of contrast and brightness enhancement. In its most basic form, this class of operations allows an image's *gray scale occupancy* to be altered. In an image processing system with pixels represented by 8-bit values, the gray scale has a brightness range of 0 to 255, where 0 equals black and 255 equals white. In any given image, however, pixel brightness may span a range of brightness not necessarily covering the entire available gray scale range.

This is often the case when imaging low-contrast scenes. For instance, an image with the gray scale distribution lumped in the center of the available gray scale indicates low contrast; few dark grays and blacks as well as light grays and whites exist. An *image histogram* plot of the brightnesses can provide information regarding the gray scale occupancy of the pixels in the image.

Brightness sliding involves the addition or subtraction of a constant brightness to all pixels in the image. *Contrast stretching* (or shrinking) involves multiplying or dividing all pixels by a constant brightness. By using these two operations, we may equalize an image's gray scale occupancy to span the entire range of the available gray scale (see Figure 4). Typically, an image of increased-contrast balance yields more apparent detail and sharpness. Brightness sliding and contrast stretching are often applied to raw images as an equalizing step to correct for poor original images due to low light and other conditions.

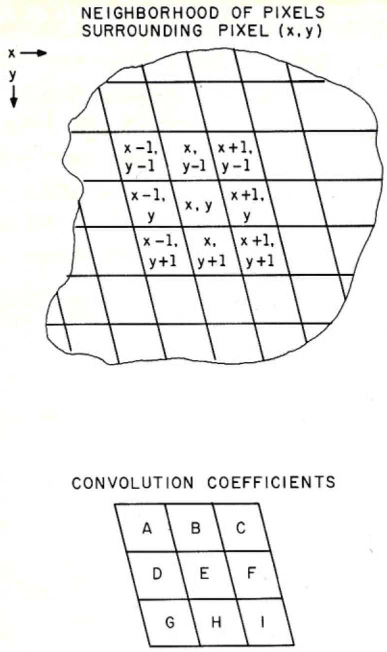
Spatial Filtering: A second class of image enhancement operations in popular use is known as *spatial filters*. These operations create an output image based on the spatial frequency content of the input image. An image may be represented as an array of two-dimensional frequency components of varying amplitudes and phases. This representation is known as a Fourier decomposition. Spatial filtering allows the separation of these components in an image. On a pixel-by-pixel basis, an output image is generated based on a pixel's brightness relative to its immediate neighboring pixels. Where a neighborhood's pixel brightnesses make rapid transitions from light to dark or vice versa, the image may be said to contain high frequency components. A neighborhood of slowly varying pixel brightnesses represents low-frequency components.

A spatial filter attenuates or accentuates the two-dimensional frequency content of an image. These operations may be used to bring out an image's high-frequency details, yielding a sharper image. Alternatively, the high-frequency details may be attenuated, yielding a low-passed image of little detail. Of great importance to machine vision systems is the ability to bring out the edge detail in an image. Edge enhancement can allow the image processing system to make edge-to-edge boundary distance measurements as well as provide the base of information necessary for automated image understanding.

Spatial filtering is carried out using *spatial convolution*, an adaptation to two dimensions of the convolution techniques all too familiar to the electrical engineer studying signal processing theory. For each input pixel within an image we calculate an output pixel based on a *weighted average* of it and its surrounding neighbors. Typically, a three pixel by three pixel neighborhood is used for this calculation although larger neighborhoods may be used for added flexibility. With the correct selection of weighting coefficients, we can form highpass, lowpass, and various edge enhancement filters.

In carrying out a spatial convolution, nine weighting coefficients are defined and labeled *A through I*. The brightness of the input pixel being evaluated and its eight immediate neighbors are each multiplied by their respective weighting coefficients. These products are summed, producing a new, spatially filtered output pixel brightness (see Figure 5). This operation is applied systematically to each pixel in the input image, resulting in a spatially filtered output image. Figure 6 illustrates common filter coefficient sets and their effects upon an original image.

Image Combination: The combination of two or more images is often useful in the enhancement process. Summing images provides the basis for image averaging, which is often used for suppression of noise within an image. Image subtraction can be used to detect the movement of objects between two similar image frames. Subtraction can also be used to remove scene objects contained in one image and not in another. Finally, Boolean logical combination of images can be used to insert portions of one image into another. Image combination of two images is done pixel by pixel over the entire image space;



$$O(x,y) = I(x-1,y-1)A + I(x,y-1)B + I(x+1,y-1)C + I(x-1,y)D + I(x,y)E + I(x+1,y)F + I(x-1,y+1)G + I(x,y+1)H + I(x+1,y+1)I$$

Figure 5. The image convolution process. In a typical image convolution process, the brightness of each pixel in the neighborhood of the pixel being examined is multiplied by its corresponding coefficient. The resulting nine values are summed to produce the new value of the pixel being examined, a weighted sum of its nearest neighbors. An output image array O(x,y) is produced by performing the calculation on each input pixel I(x,y) using an appropriate software algorithm or special-purpose hardware device.

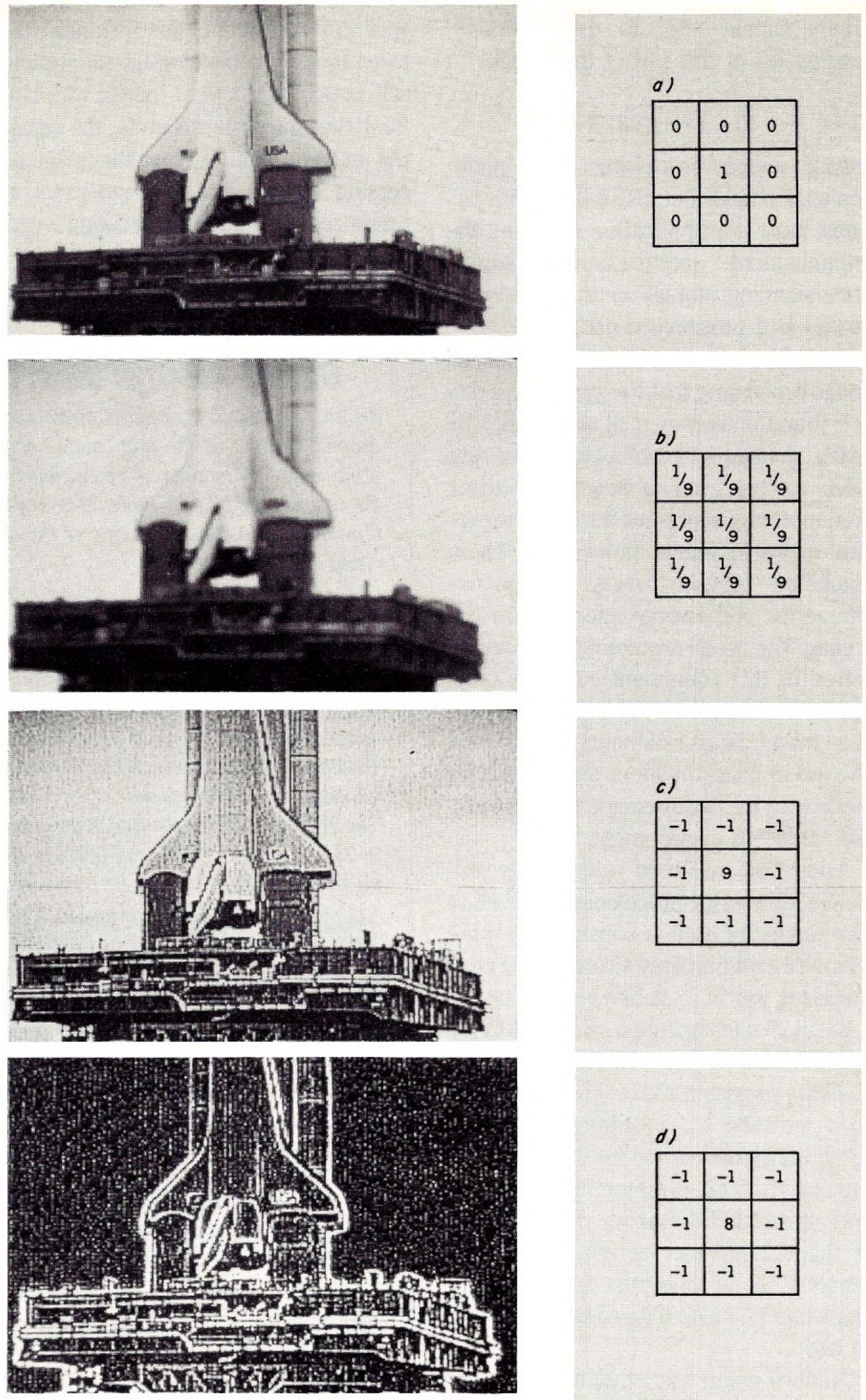


Figure 6. The effects of simple convolutions. Each choice of an array of convolution coefficients has a different effect on the output image. Here we show four such choices as an image at the left and its convolution matrix at the right. In the first example (a), we show the case of "no change." If the only non-zero coefficient is 1 in the center of the matrix, we get the original image. At (b) we show a convolution which simply averages the nine elements of each neighborhood, reducing image detail. At (c) is a high-pass filter showing enhanced detail. And finally, by altering one coefficient in the (c) matrix, we produce the edge-enhanced convolution of (d). Edge enhancement is the first step in many algorithms for pattern recognition useful in robotics.

corresponding spatially located pixels from each input image are combined to form a composite output pixel at the same spatial location in the output image.

Geometric Operations: Geometric scaling, translation, rotation, and perspective manipulations of images are typically used prior to combination or enhancement operations. Often these operations are used in order to bring two images of similar content into register. Patching of several images into one composite may be facilitated by these operations, analogous to cutting and pasting several prints together into one.

Geometric operations used upon image arrays are usually handled by software routines similar to those used by computer graphics packages. Of major importance to images, though, is that of spatial interpolation. For instance, when an image is rotated, its square input pixel grid locations will generally not fall onto square grid locations in the output image. The actual brightnesses in the output pixel locations must be interpolated from the spatial locations in which the rotated pixels were calculated to land. Differing interpolation schemes can produce rotated images of varying quality.

The operations described here are simply the most commonly used functions in digital image processing. Many others, including derivatives of these operations, are in use today, covering a wide variety of applications. Often highly customized routines are designed in order to work with the input images available to a particular application and the desired end results. The reader interested in expanded

knowledge of these operations and many others should refer to the *additional reading* list at the end of this article.

THE APPLICATIONS

Digital image processing is a multi-application field. Because it deals with pictures, most any application requiring the enhancement, restoration, analysis, understanding, storage, or transmission of images is a prospective use.

Probably the most visible form of digital image processing that the public sees daily is found on commercial television. The lavish geometric manipulations of live video on the evening news or sporting event coverage represent the use of expensive real-time image processors. These machines perform image perspective alterations and special effects upon the scenes. The image-processing hardware involved in this equipment currently costs upwards of $50,000. The networks and local broadcasters rationalize their expensive use as image builders, an essential ingredient in the highly competitive commercial television environment.

Aside from real-time video image processing, the image processors described in this article are used in considerably more technical environments. Probably the most prevalent use is in geographic mapping. LANDSAT satellite images of the Earth are collected daily in high volume requiring expedient processing and archival. These images must be enhanced, colored, data compressed, and stored for distribution to the end user, often researchers in the oil and agricultural industries. The archiving of the vast number of images for later retrieval alone presents an interesting challenge in image data compression and storage.

Medical diagnostic equipment such as Computerized Axial Tomography, ultrasound scanners, and X-ray imagers use digital image processing extensively in their processes. CAT scanners in particular require large amounts of geometric image processing. These systems derive synthetic cross-sectional images from a set of originals taken through low-intensity X-ray photography around a subject. Medical imaging equipment often employs custom hardware facilitating the specific image processing tasks required by the application.

Factory automation applications have employed vision systems to monitor and coordinate automated assembly and inspection equipment. For instance, in an assembly line monitoring system, a camera will "watch" a conveyor loaded with parts. Each time a new part is under the camera, the image is captured into the image processing system. The host computer can preprocess the image by executing an edge enhancement operation.

From the edge information it can then perform analysis operations such as the measurement of certain predetermined physical dimensions of the part. These measurements are used to reject or accept the part based on dimensional tolerances set by the user. This application of digital image processing has greatly enhanced the factory inspection process by simultaneously automating it and improving the measured accuracies.

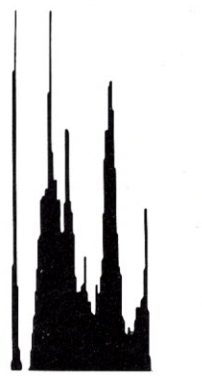
Using Histograms to Adjust the Gray Scale

An important image analysis operation is the image histogram. *The histogram gives a graphic display of the gray scale occupancy of an image. The two axes are labeled* brightness *and* number of pixels, *where the units of brightness range from 0 to 255 in the case of an 8-bit gray scale. This graph allows us to view an image's brightness distribution, helping in the application of the appropriate brightness sliding and contrast stretching enhancements.*

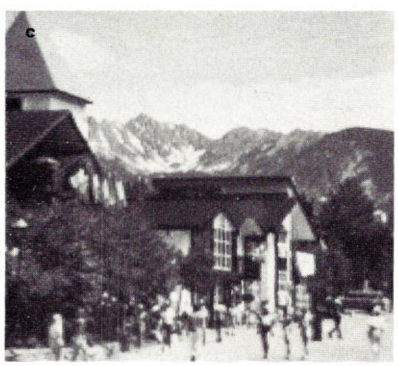
The typical objective is to enhance an image's contrast such that the gray scale occupancy spans the entire range of the gray scale. Looking at the histogram plot, the correct amount of sliding and stretching becomes evident. Photo a and Figure b illustrate a low contrast image and its histogram. As evidenced by the clump in the center of the histogram, few low brightnesses below 55 and high brightnesses above 146 exist in the image. Therefore, the gray scale occupancy of this image resides between 55 and 146. To enhance the image such that its gray scale occupancy spans the range from 0 to 255, we may do a brightness slide of −55 followed by a contrast stretch of 256/(146−55)=2.8. The effect is to force the lowest brightness in the image to 0 and the highest brightness to 255. The others follow in a linear stretch between 0 and 255. Figure d and Photo c illustrate the resultant image with equalized contrast and its histogram.

a

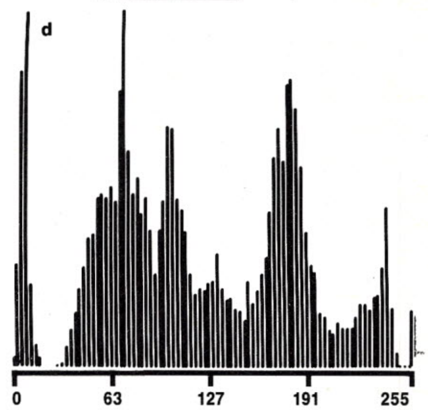
b



c



d



An experiment in histograms. At (a) is an original of a photograph with relatively low contrast. When we do a count of the number of pixels at each brightness level we produce the histogram (b) which shows a cluster of pixel values in the range 55 to 146 out of a total possible range of 0 to 255. By sliding the brightness down to 0, then doing a contrast stretch by scaling the resulting range to the full range 0 to 255, we produce the histogram (d) of the enhanced image (c) with a gray scale that occupies the entire gray scale range, indicating improved contrast.

THE FUTURE

Digital image processing is a growing field and has been for years. From its roots in expensive custom applications, the trend, spurred by lower-cost semiconductor technology, has been toward less expensive products. Initially, stand-alone systems selling in the $50,000 to $100,000 range made their appearance in the late seventies. The early eighties brought $10,000 boards for high-end microcomputers such as Multibus-compatible systems. Today, inexpensive peripherals for the personal computer market are beginning to emerge.

In particular, vision peripherals for the IBM PC have been targeted by several manufacturers, with more on the way. These products range from simple video digitizers requiring external display boards to full-blown capture, storage, and display peripherals. Prices for these units range from about $300 to $3000, with quality and features commensurate with price. The less expensive boards typically digitize to lower resolution and do not provide instantaneous image capture from a live video source. The more expensive boards give full 512 line by 512 pixel by 8 bit per pixel resolutions, instant capture and display, and some hardware processing features. Additionally, many boards provide color look-up tables in the output video path, allowing pseudo and false color image display.

The availability of processing software is also maturing to the point that full image processing packages especially for personal computers are now available. The era of the personal computer as an image engineering work station is upon us. In the next few years, personal computer digital image processing stations will be more prevalent than ever before. In a snowball effect, this availability will promote more activity in new application areas that, in turn, will instigate the development of better and less expensive systems with wider applications.

Gregory A. Baxes is an engineer in the Research and Development department at American Television and Communications Corporation where he is actively involved in the design and development of digital video systems. His past work has included the design of intelligent satellite image analysis hardware for NASA, video scrambling security systems for the cable television industry, and low-end microcomputer hardware and software design for digital video acquisition and processing systems. He also consults with his own firm, where he is pursuing color image compression techniques for the transmission and archiving of video still imagery. He has written a book entitled *Digital Image Processing: A Practical Primer*, Prentice-Hall, 1984.

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PC-BASED IMAGE PROCESSING

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Image processing is the process of producing useful symbolic descriptions of a visual image from real-world data. The fundamental objective of such an application is the visual enhancement or statistical evaluation of some aspect of an image that is not immediately apparent in its original form. Recent trends indicate that as industrial systems broaden their horizons to include computer-based processing, vision systems will become an integral part of the total factory automation concept.

Machine vision systems must be capable of image sensing, image analysis, and image interpretation. Flexible image processing systems are capable of automatically acquiring information about an object, measuring its features, recognizing an object within a scene, and making decisions based on the acquired data.

In an image processing system, video cameras are linked to computers, picking up patterns of light and dark. The resulting images can be processed by a computer to perform enhancement or contrast operations for a higher-quality image. The computer analyzes the images and extracts the required information, such as the presence, position, orientation, and identity of the object. Most common in today's factory environment are video cameras linked to robot arms and manipulators.

Over the last few years, industrial robots have evolved into intelligent computer-driven interfaces, primarily due to the need for improved quality and productivity on the factory floor. The most important benefits provided by industrial robots are increased accuracy and consistent quality. The robot provides precise repetition of certain functions and is impervious to human frailties such as boredom, fatigue, or carelessness. An intelligent, computer-based robot vision system can potentially handle such tasks as identifying parts, assembling and sorting them, inspecting and grading them, and taking corrective guidance and control action to maintain uniformity.

KEY COMPONENTS

Effective image processing and analysis applications, whether in the laboratory or on the factory floor, require large computational and data storage capacities. Until recently, mainframe computer systems (or at least powerful minicomputers) were required for sophisticated processing and analysis. Mainframe and minicomputers have been used to process medical images, military surveillance photographs, and satellite images. The introduction of personal computer-based image processing systems will prove especially attractive for other, more price-sensitive applications, such as robotics, manufacturing and automated inspection, and security systems.

An image processing system's fundamental purpose is to digitize, store, and process an image to extract information about a scene. In robotics applications the image processor must process the scene in a timely fashion to generate feedback information for a robot control system. A typical system configuration includes an overall control computer, a video camera for image scanning, a video I/O interface to digitize and display the image, an optional arithmetic coprocessor for high-speed calculations, and image processing software.

Vidicon or solid-state cameras are the main inputs to a computer vision system. An image is scanned as an array of light intensities which are converted into analog electrical signals by the camera. If performed at "real-time" speeds, a new image will be scanned 30 to 60 times per second and fed into the image processing computer's video I/O (frame grabber) interface.

The video I/O interface, for example the Data Translation DT2803, consists of a high-speed, flash A/D converter for image input and a multiplexed D/A for color or monochrome image display. The flash A/D converter takes the scanned video image and converts it into a numerical representation suitable for computer processing. The digitization in the Data Translation product takes place in 1/30th of a second. This defines a basic granularity of the "real time" response possible with the system, a fundamental sampling rate for the images.

The digital information representing the original video scene is stored within the image processing system's memory in a "frame store". Data is sent to and from the frame store memory by the camera input, display monitor, image processing control computer, and internal image processing hardware (such as the video I/O interface). The memory required to capture and display the images in the frame store is determined by a one-to-one mapping of scene picture elements (pixels) onto words of memory.

For example, an image that has a resolution of 256 lines by 256 elements requires 65,536 units of information to be stored in memory. Since each unit in a reasonable image represents a light level or a color

value, each point is represented by an integer in the memory array. If we use 8-bit integers, a byte of memory corresponds to each pixel. In this case, the actual digital picture information requires 65,536 bytes of computer storage. This size fits well in today's 8086/8088 based 16-bit personal computers like the IBM PC, where memory segment sizes are 65,536 bytes. Attempting to use more than one memory segment of information per image frame would dramatically increase processing time. (Other 16-bit or 32-bit computer architectures like the Motorola M68000 do not segment memory and thus do not have "magic" frame size limits such as the 8086/8088 segment size.

THE DT2803 VIDEO I/O BOARD

Data Translation's DT2803 IBM PC/XT/AT compatible video I/O board shown in Photo 1 accepts standard RS-170 (or 50 Hz CCIRR) camera inputs. An on-board phase-locked loop is used to synchronize the DT2803's video timing with the camera. An optional internal sync signal is available for applications where a camera input is not always desired (e.g. VCRs and VTRs).

Photo 1. The Data Translation DT2803 video I/O board connected to an IBM PC and external color monitor. The use of a monitor provides a means to follow the image processing operations via a displayed output of internal data. This provides a link between the system and its human operators.

The DT2803 uses a low-power (CMOS) flash A/D converter to digitize the image. (Due to the peculiarities of the standards used in modern television, 60 Hz television signals are digitized into 61,440 6-bit pixels representing 240 lines by 256 pixels; 50 Hz signals are digitized into 65,536 pixels representing 256 lines by 256 pixels.) The input pixel values are subsequently converted into 8-bit values through one of eight software selectable look-up tables. Several of these look-up tables are predefined with special preprocessing operations. The remaining look-up tables can be programmed for point processing operations like image averaging or logarithmic conversions.

The DT2803 stores the digitized video image in a 256 by 256 by 8 frame memory. Depending on the particular input look-up table chosen, the frame store memory can right-justify the 6-bit pixels from the A/D and store each as an 8-bit value. The extra two bits per pixel can be used for write-protection or to add additional information to the image, such as user-defined boundaries. The resulting 8-bit value can be processed either by the image control computer, by a high-speed coprocessor, or by the DT2803 output look-up tables.

For applications requiring high-speed computational capabilities beyond those of the IBM PC's 8087 (or the PC/AT's 80287), the DT2803 provides external digital ports. Information can be acquired by the video I/O board and passed directly to a plug-in coprocessor directly through this external path. The information never passes through the IBM PC bus or affects the image control computer. Passing the information over this port to a high-speed coprocessor removes the speed limitations imposed by the IBM PC bus. It also releases the IBM PC's processor for other tasks.

Gray level and color intensity control can be achieved by using one of the DT2803's four output look-up tables to map a stored image's pixel values into output pixel results. The data generated by the output look-up tables is dependent on the information loaded into the tables by the host computer before the operation. An example of a common mapping function is a binary contrast enhancement, where all pixels below a certain brightness are set to black and all pixels above this value are set to white. This process is particularly useful in applications requiring that an object contrast sharply with its background.

For final display, the DT2803's output converters allow a set of 256 display attributes to be chosen out of a possible 4096. The 4096 attributes consist of 64 colors, each of which can be displayed at 64 different intensities.

CONTROL SOFTWARE

Data Translation's optional VideoLab software package includes an interactive tu-

torial and callable subroutine library that eliminates the need for users to program the hardware at the machine level.

The following functional operations are supported by VideoLab and are easily integrated into the total machine vision application via C, FORTRAN, Pascal, or BASIC:

- real-time image acquisition
- image data display
- image data movement between frame storage buffers
- simple operations on the data, including baseline correction, merging, differencing, and swapping
- histograms and convolutions, including lowpass, highpass, and Laplacian filters
- image storage and retrieval to and from host computer disk files
- look-up table manipulation

IMAGE PROCESSING IN ROBOTICS

Generally, industrial machine vision application processing requirements are limited to simple, repetitive processes that focus on object detection, object location, pattern recognition, and image enhancement. The desired image processing capabilities can vary greatly among applications. The most common functions include: shape identification, distance measurement, orientation determination, and motion detection. Robots equipped with vision capabilities are used primarily for automated inspection and assembly, welding (especially spot welding in the automotive industry), machine loading and unloading, and paint spraying.

A vision-based robot manipulator can record its position in terms of the displacement of its end effector along the axes of a preprogrammed reference image. Comparing the end effector's various positions to several stored references allows a variety of activities to be performed, such as object tracking and automatic calibration. Of primary importance, though, is that the basic capabilities of a computer-based robot vision system can be adapted to the requirements of new classes of tasks by simply loading new programs into the host computer. With the availability of a personal computer, the user can program the operation of the robot in a high-level language, such as with VideoLab, and store it for later use. This eliminates the need to redesign and rebuild the robot's complex control electronics.

The processing of gray-scale images at high resolution often provides impressive results but, inevitably, this is achieved at the expense of processor cost and processing time. Dedicated image processing systems address the problem of processing speed, but at a high price. With today's low cost computer hardware/software technologies, both laboratory researchers and industrial users can start to take advantage of image processing with a standard system architecture that is both flexible and expandable.

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POLAROID ULTRASONIC RANGING SENSORS IN ROBOTIC APPLICATIONS

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An important element of any robotic system is its capacity to interact with its surroundings, both human and inanimate. Human interaction occurs at two levels: the designer first defines the basic framework for the robotic system's operation—its ability to move or sense in a particular manner. The user of the robotic system must then control the run-time operation, that is, how, when, and where to move and sense. (This second level could also include autonomous operation.) The inanimate environment (such as walls) in the robot's immediate vicinity certainly affects its operation.

In general, the robotic system affects its working environment by means of various actuators. It utilizes sensors to determine the effects of those actuators. Examples of actuators include motors for movement, arms and end effectors for grasping, and sound producers for alarm or status indicators. Photocells, limit switches, and microphones are examples of the sensors considered.

This article focuses on the use of one type of sensor, the Polaroid ultrasonic distance ranging sensor, and the role it can play in serving both as sensor of the environment and as human control input.

THEORY OF OPERATION

The Polaroid Ultrasonic Sensor is an electromechanical system used commercially to focus a camera by measuring the distance from the camera to the subject. It operates by producing a burst of inaudible sound waves from the electrically excited diaphragm of the transducer. This sound then propagates through the air until it encounters the subject. A portion of the sound incident on this object is reflected back to the transducer and is detected by the associated electronic circuit board. The distance to the subject can be deduced from knowledge of the round-trip travel time of the sound and the speed of sound through air.

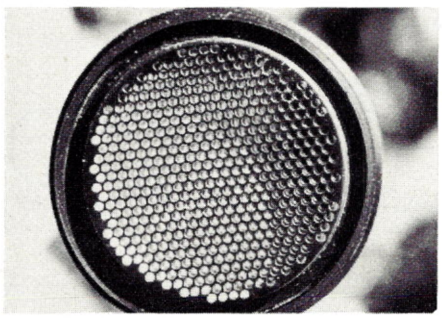


Photo 1. The Polaroid Ultrasonic Distance Ranging Sensor consists of the acoustic transmitter shown in this picture and the ultrasonic circuit board that drives it.

The two primary elements of the Polaroid Ultrasonic Sensor are the acoustic transmitter and the ultrasonic circuit board that drives it. Together, these components are capable of detecting the presence of and distance to objects within a range of approximately 11 in. to 35 ft.

The sensor transducer is a device that acts as both a producer and detector of ultrasonic energy. A special stretched foil forms the vibrating element that transforms electrical energy into sound waves and the returning acoustic echo back into electrical energy. It is protected by a 1.5 in. diameter perforated metal housing.

When the ultrasonic circuit board is activated, the transducer emits a sound pulse and awaits the reception of an echo returning from whatever object the sound pulse has struck. In the standard unit, the emitted pulse is actually a high-frequency pulse train or chirp. Four carefully chosen ultrasonic frequencies (60 KHz, 57 KHz, 53 KHz, and 50 KHz) are used to minimize single frequency signal cancellation effects produced by some targets at certain distances.

The ultrasonic circuit board controls the transducer's operating mode: transmit, receive, or standby. It is composed of three major sections: the digital circuit, the analog circuit, and the power section, each of which is implemented in a single custom-integrated circuit.

Figure 3 shows the system block diagram. During the transmit portion of the operating cycle (one millisecond) the circuit board digitally constructs the pulse train, amplifies it to approximately 150 V, and sends it to the transducer. After generating the chirp, the sensor switches operating modes from transmit to receive and is ready to detect a returned echo. After receiving the echo, the sensor converts the sonic energy into an electrical signal which is amplified by the analog section, detected by the digital electronics, and presented as an output signal.

The energy present in the echo varies as the inverse fourth power of the distance between the sensor and the object. For the

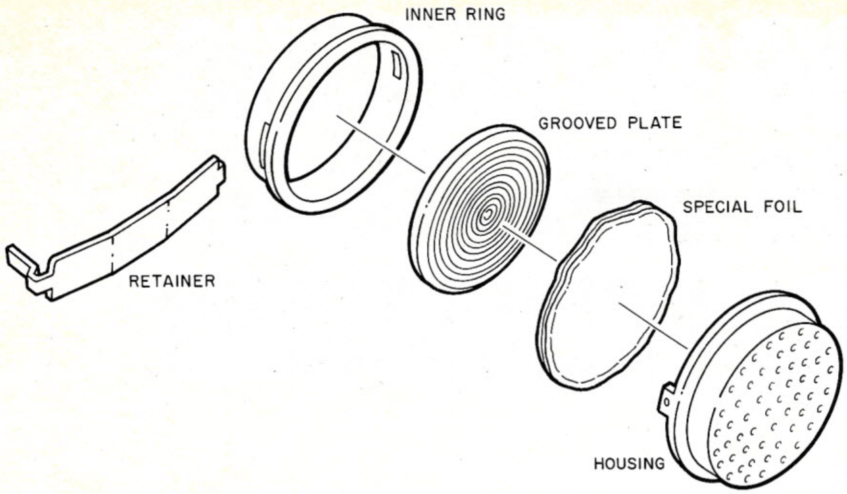


Figure 1. The transducer portion of the Polaroid sensor is composed of a special stretched foil vibrating element that both produces and detects the ultrasonic energy and a perforated metal protective housing.

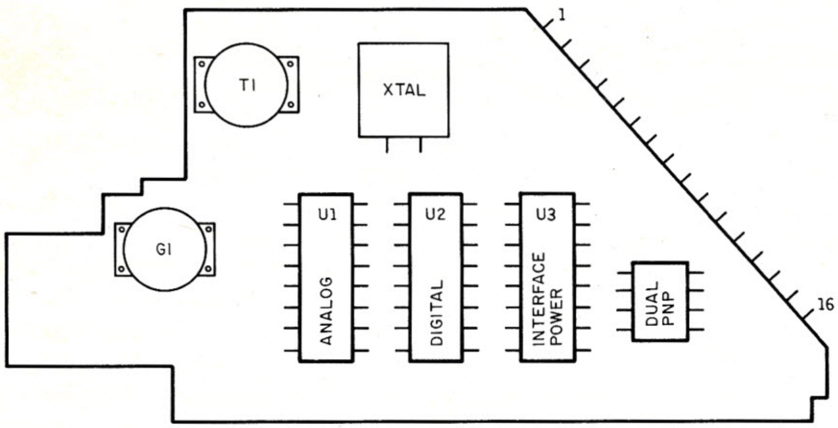


Figure 2. The ultrasonic circuit board is composed of three main sections: the digital circuit, the analog circuit, and the power section—all implemented in custom ICs.

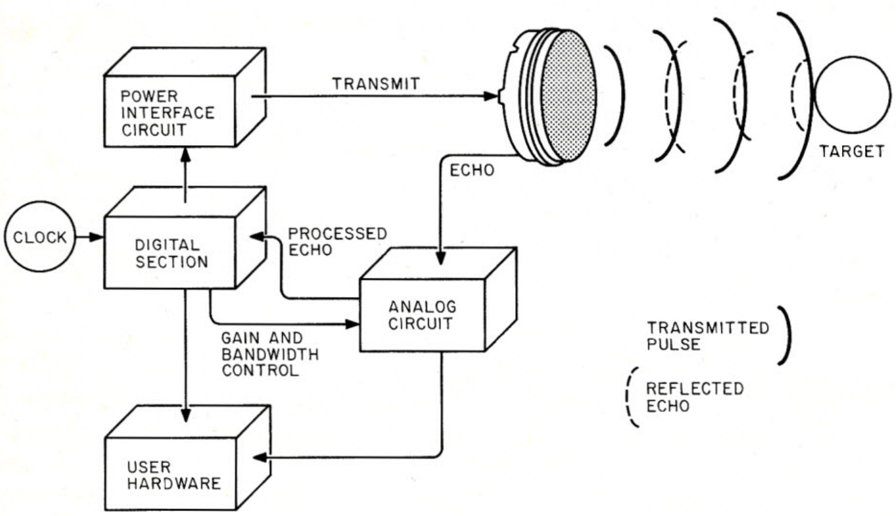


Figure 3. The system block diagram shows the functional elements of the ultrasonic distance-ranging system, including the transducer which transmits the pulse signal and receives the reflected echo.

minimum and maximum distances given, this represents a ratio of 2 million. In order to detect both near and distant objects therefore, the circuit board employs a variable gain, variable bandpass amplifier. Immediately after transmitting, the amplifier is in a low gain, narrow bandpass configuration. If no echo is initially received, the gain is increased and the bandwidth broadened. This action maintains a constant sensitivity over the entire operating distance range of the unit.

The circuit board has two outputs and one input. The power input (pin 9) is a 6 V signal that initiates a transmit/receive cycle. After this signal is applied, the transmission output (pin 16 XLG) indicates the transmitted signal. The leading edge of this signal marks the start of actual ultrasonic emission. At some later time, the detected echo (pin 15 FLG) line is driven high as the returned sound is processed. This signal eventually becomes active, even if no echo is received.

The Polaroid system's ability to detect objects depends on many factors: target size, target orientation, and the target's acoustic surface characteristics. A large flat target with a reflective surface parallel to the face of the ultrasonic transducer is easiest to detect. If, on the other hand, the sound strikes a surface at an angle, a portion of the acoustic energy bounces off the surface away from the sensor and is lost. If this angle is too shallow, not enough energy will be reflected back to the sensor, and the electronics will not detect the echo; the target becomes sonically invisible. In general, an object will be difficult to detect if it does not reflect enough of the transmitted sound back to the transducer because of its small size, distance, or reflective properties.

The echo detection circuitry is based upon the amplification of the received sound energy. When this energy exceeds a predetermined threshold, the echo line becomes active, independent of any periodic clock timing signal. Although the resolution is not affected by the receive circuitry, it is influenced by the transmission method. As previously stated, the generated ultrasonic signal is actually a train of 56 pulses that requires 1 ms to send. During any particular ranging, the echo of the first pulse of this train might be the one detected by the receiver. In subsequent distance determinations, the echo from another pulse in the train might be sensed. Thus, in the worst possible case, an uncertainty of 1 ms (6.6 in.) is contributed by this method.

A final resolution-dependent phenomenon involves the surface geometry of the target and the transducer beam pattern. If the object surface geometry is irregular, the echo from one section of the object may trigger the receive electronics on one ranging. On a subsequent ranging, another section (at a different distance) might be detected. For example, if the distance to a person's face was to be determined, the ultrasonic echos from the cheeks, fore-

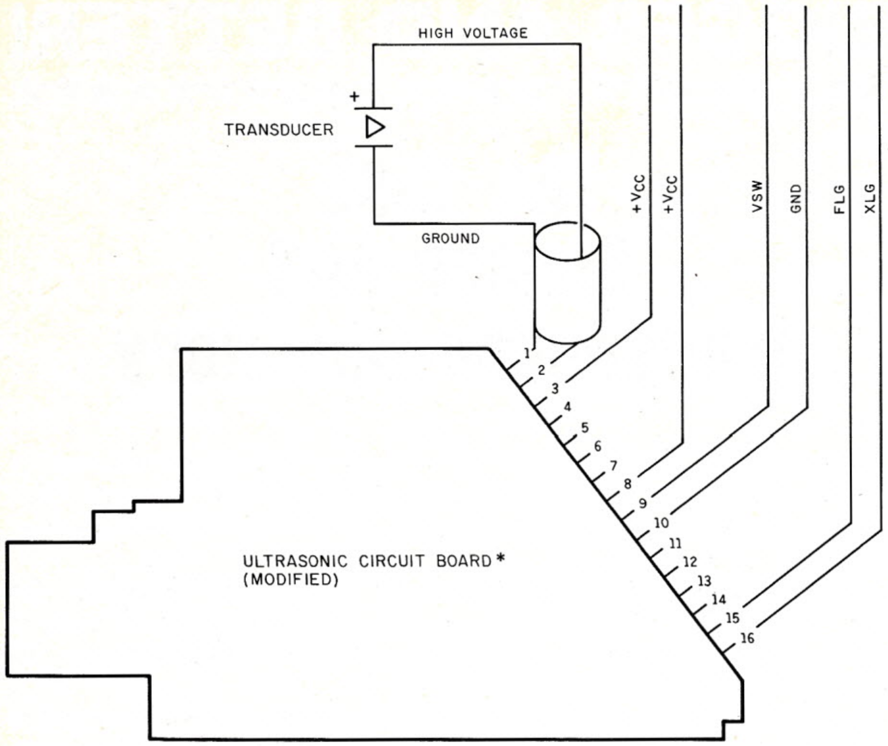


Figure 4. The ultrasonic circuit board has two outputs: XLG, the transmitted signal and FLG, the detected echo, and one input: VSW, the 6 V input.

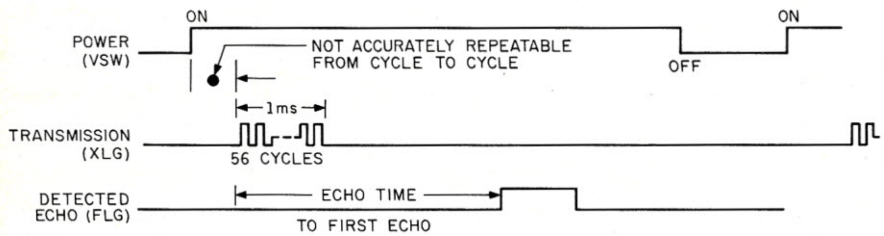


Figure 5. The leading edge of the transmission signal shown on this timing diagram marks the beginning of the actual ultrasonic emission.

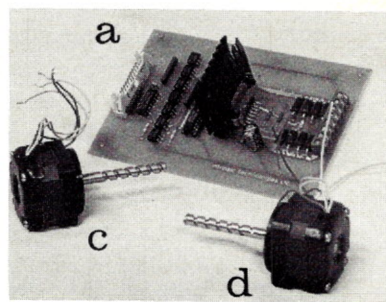
head, eyeglasses, and nose all compete for detection. The first echo that contains sufficient energy to exceed the threshold produces a valid output signal.

The Polaroid Ultrasonic Sensor system appears insensitive to environmental sounds and interferences such as the radio frequency energy generated by microcomputers and motors. Other ultrasonic sources likewise have no effect on the operation. Raindrops do pose a problem, however, since they reflect ultrasound and affect distance readings.

HARDWARE

The Ultrasonic Ranging System Designer's Kit from Polaroid includes two Polapulse batteries with holders, two transducers, one circuit board, and a display board. Although it is adequate for experimentation, it does not include enough hardware or instructions to easily interface the sensors to a microcomputer system. Such an interface can be constructed from readily available parts and integrated circuits, though, and the one described here includes facilities for software control of data acquisition rate and operation using a sophisticated counter/timer chip. The resultant interface can obtain distance information from two sensors without requiring the microcomputer to dwell in a counting loop during ranging.

The interface of the Polaroid Ultrasonic Sensor to a microcomputer system involves several functional elements: the translation of circuit board outputs to TTL levels, the generation of the transmit signal, the con-



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struction of a ranging signal, and the conversion of this signal to digital form. These phases are accomplished as follows.

The AMD 9513 System Timing Controller is used both to generate the acquisition rate signal and time the width of the ranging pulse. The integrated circuit itself consists of five counter/timer sections and a programmable divider. One section of the counter/timer is employed in the ranging task, while another produces the rate signal. When it is connected to a microcomputer system via I/O ports, it becomes an effective way of interfacing the Polaroid Ultrasonic Ranging sensor to an integrated robotic system.

Among the many operational modes of the 9513, Mode N translates the pulse width ranging waveform into a 16-bit digital value a microcomputer can manipulate. In this mode, a separate clock signal is generated using the chip's frequency divider mechanism. The number of clock cycles that occur when the ranging signal is active is accumulated and stored in a register. Old data is replaced with new with each subsequent ranging. In this manner, the processor can process distance ranging information simultaneously with new data acquisition. The digital resolution of the range depends on the clock signal frequency. Using a 400 KHz clock frequency, each count represents 1/60 of an inch.

Two output signals and one input signal form the basis of the Polaroid circuit board operation. The power (PSW) input is a 6 V signal that initiates a transmit/receive cycle. It should be capable of delivering 2.5 A and have a quick rise and fall time. After this signal is applied, the transmission (XLG) output shows that a signal has been transmitted. Its leading edge marks the start of the actual ultrasonic emission. At some later time, the detected echo (FLG) line is driven high as the returned sound is processed. The timing of these signals is shown in Figure 4. A single transistor circuit is required to convert the XLG and PLG signals to standard TTL voltage levels. (See Figure 6.)

Generating the VSW signal first requires the production of software-controlled periodic square waves by a section of the AMD 9513 counter/timer chip. The remainder of the power section converts this signal to a 6 V signal that drives the VSW input on the Polaroid circuit board. (Refer to Figure 7.) The counter/timer output is conditioned by an open-collector buffer.

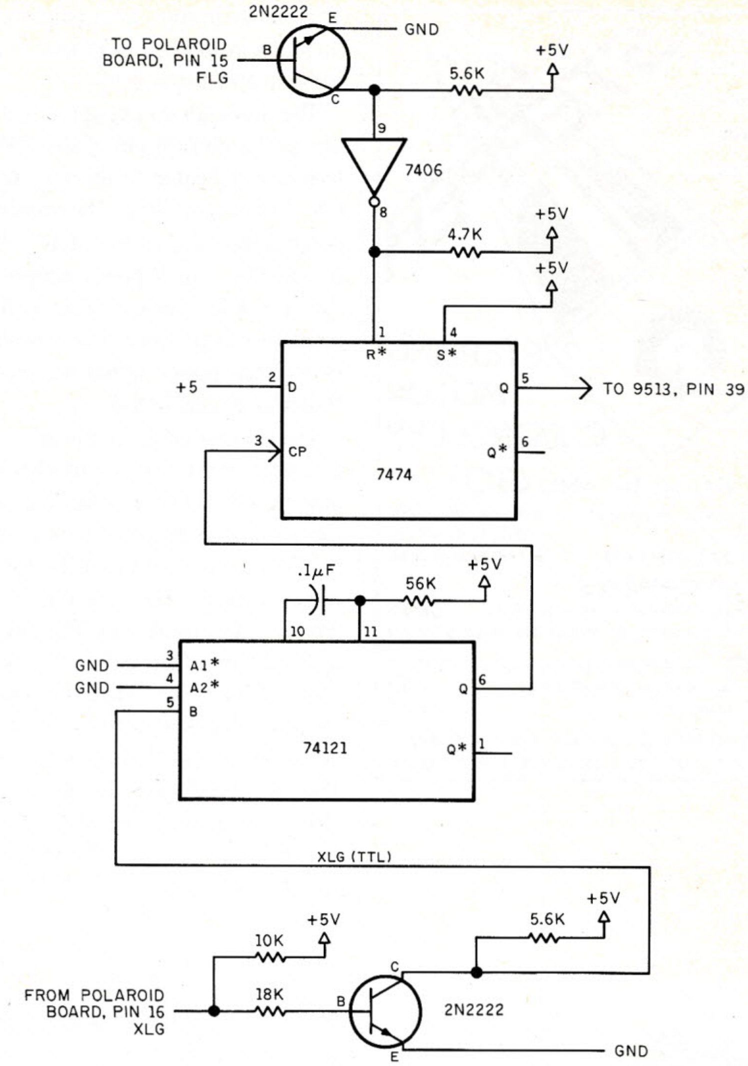

Figure 6. This circuitry shown is necessary for converting signals to proper TTL levels and also for the receive cycle of the system.

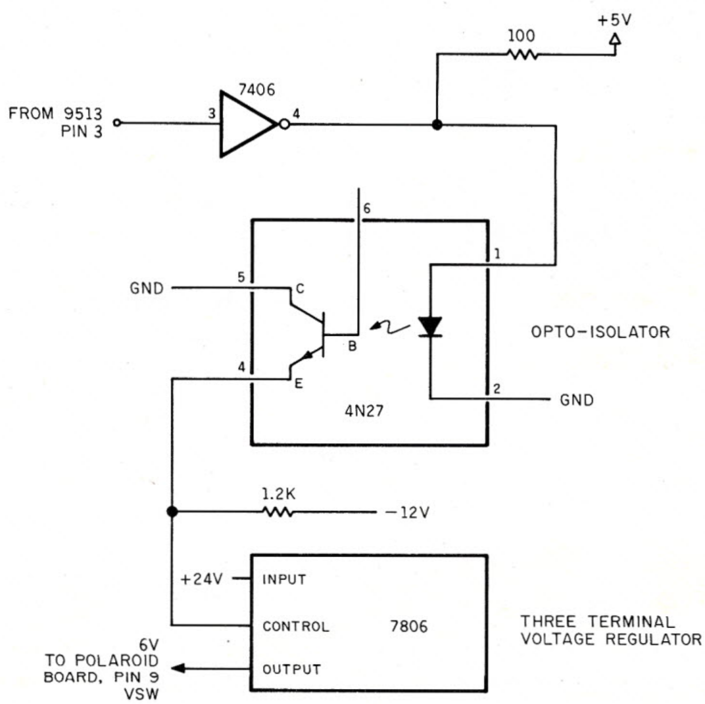

Figure 7. The VSW signal needed by the Polaroid board is initially generated as a square wave from the AMD 9513.

This signal, in turn, intermittently grounds the current to the LED input of an opto-isolator and turns it off.

The transistor output of the opto-isolator brings the control pin of the 7806 three-terminal regulator to ground, producing 6 V at its output. When the transistor stage is not driven, the 7806 output is biased to 0 V by the −12 V power supply through the 1.2 KΩ resistor. The regulator is employed to produce a fast-rise-time low-impedance power signal required by the Polaroid circuit board.

The receive circuitry produces a signal that goes active coincident with XLG and inactive with FLG. The key component is the 7474 R–S flip-flop. It is gated on by the 74121 one-shot multivibrator, a signal whose leading edge represents the start of ultrasound transmission. The 7474 is reset upon receipt of the echo. The active portion of the resultant signal thus represents the round-trip time of the ultrasound signal out to the target and back to the sensor. This signal is directed to the counter/timer where this active pulse width is converted to a 16-bit range value. The timing diagram for the signals discussed is shown in Figure 8.

SOFTWARE

The FORTH programming language is frequently used in industrial process control applications. It features a highly interactive development environment and produces compiled code that executes quickly while retaining high-level programming quality. In many ways, a robotic system resembles a process-control system in that both are concerned with the real-time operation of actuators under the supervision of a human user or sensory environmental information. FORTH has been used and has proven its utility and flexibility in the development of devices using Polaroid ultrasonic distance-ranging technology. The following distance-ranging software is coded in FORTH.

The first piece of software involves setting system constants and defining the counter/timer parts (similar to equates in assembly language). In this example, the 9513 data port is set to 50H and its command/status port to 51H:

```
HEX
50     CONSTANT  PBASE
PBASE CONSTANT  DATA
PBASE 1+ CONSTANT COMMAND
```

Next, the master mode register of the counter timer is initialized by sending the proper data to its command and data ports:

```
: INIT 17 COMMAND P!
0 DATA P!
ODO DATA P! ;
```

Channel #1 is programmed to be a software-setable square wave generator. The output of this section drives the VSW input to the Polaroid circuit board and thus sets the acquisition rate of the board.

```
: RATE (N-)
  [ DECIMAL ] 20005 10 ROT */
  [ HEX ] 100 /MOD SWAP
  1 COMMAND P!
    22 DATA P!
    OC DATA P!
  9 COMMAND P!
    DATA P!
    DATA P!
  21 COMMAND P! (arm counter) ;
```

In operation, this word is called with a number on the stack that is manipulated by the internals of RATE to produce two values that command the counter to produce a square wave of the desired frequency. Thus, the FORTH command: `10 RATE` results in a square wave VSW signal that causes the Polaroid ultrasonic sensor to perform ten rangings per second.

Next, channel #2 is configured in mode N, the mode that counts the number of clocks that occur during the active portion of the distance signal.

```
: MODE-N
  2 COMMAND P!
    OAA DATA P!
    8C DATA P!
  OA COMMAND P!
    0 DATA P!
    0 DATA P!
  66 COMMAND P! ;
```

Reading the distance is just a matter of retrieving the contents of the channel #2 hold register.

```
: READ (-N)
  12 COMMAND P!
    DATA P@
    DATA P@
    100 * + ;
```

A short program can now be written to display the distances on the console until

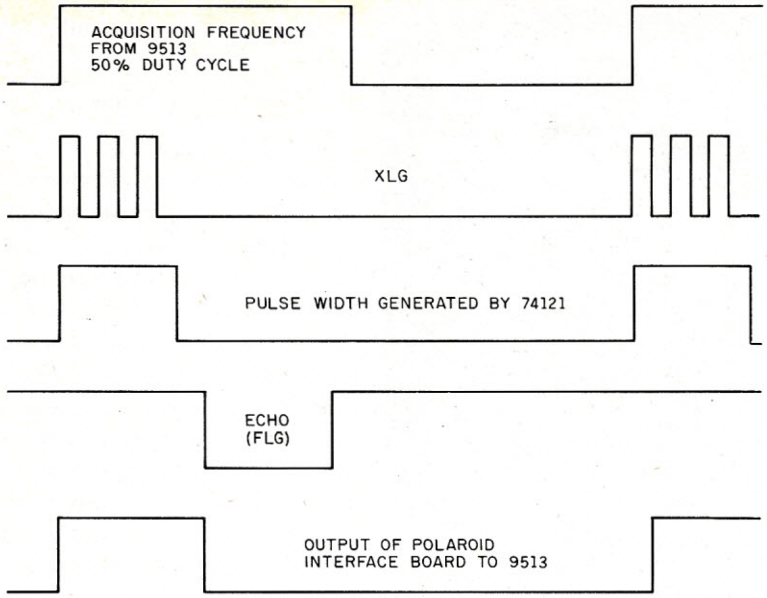

Figure 8. The timing diagram shows the frequency and pulse width of the 9513 output, the transmission output, the output of the one-shot, the echo, and the Polaroid board output.

halted by a key press. (The period, ".", prints the number on the stack, while CR sends a carriage return and line feed to the console.)

```
: TEST INIT 10 RATE MODE-N
  BEGIN
    READ . CR
    ?TERMINAL
  UNTIL ;
```

In a robotic application, the value obtained by READ can be used in many ways.

```
: AVOID INIT 10 RATE MODE-N MOTORS-ON
  BEGIN
    READ
    MINIMUM-DISTANCE <
      IF RANDOM-TURN THEN
    0
    UNTIL ;
```

In this example, a hypothetical robot control system has been created. (RANDOM-TURN would have been previously defined.) If the robot encounters an obstacle at a distance less than the specified constant MINIMUM-DISTANCE, it turns in a random fashion to avoid the obstacle. Other algorithms, limited only by the designer's imagination, can certainly be implemented.

ROBOTIC INTERACTIONS

Detection of environmental-based or human-initiated distance data is an integral part of the safe and efficient operation of a robotic system. The system's ability to acquire distance information thus serves two purposes: sensing environmental conditions and receiving human control information. The most obvious use of ranging data is to detect the presence of and distance to objects in the robot's field of operation. This information provides the structure of the robot's surroundings and can facilitate the approach to an object (such as a barrier or a person) or may signal the existence of an obstacle in the robot's path. Alternatively, an examination of the distances to objects around the robot may indicate the robot's longest unobstructed travel path.

HUMAN INTERACTION

Distance sensing to human body parts is a frequently overlooked use of the Polaroid Ultrasonic Sensors. For instance, the range to a person's hand could be used as an instrument. A smooth and immediate control signal produced in this way requires no mechanical contact with the operator. This control signal could vary proportionally operating parameters such as the voltage, speed, volume, frequency, or brightness of the device to which the distance ranging unit is connected.

The use of two body parts or one body part that moves in several directions can produce a two degree of freedom control signal. For example, the position of a cursor on a video screen can be controlled

Photo 2. The pair of transducers mounted on the wheelchair monitor the individual's head position. Changes in position are translated into motor control signals for the electric wheelchair. The unit containing the circuitry is just visible behind the back of the seat.

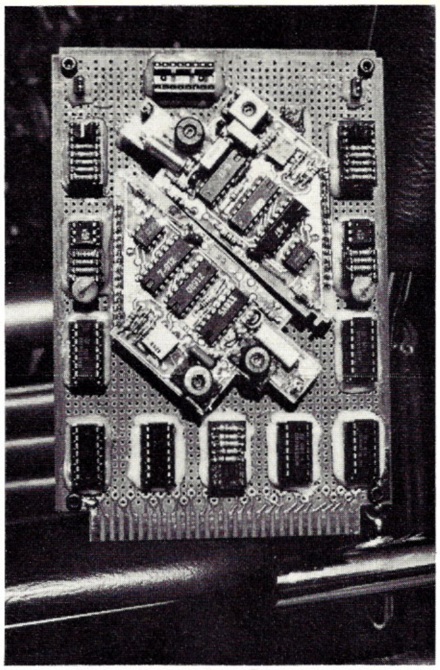

Photo 3. Two ultrasonic circuit boards necessary for controlling two Polaroid distance ranging sensors are shown on a single wiring board.

by shoulder positioning as detected by suitable mounting of sensors; one above and the other in front of the shoulder. The up-down position of the shoulder could vary the cursor's vertical placement, and the forward-backward motion of the shoulder could be translated into left-right cursor positioning.

In one application for severely disabled individuals, head position is monitored by a pair of ultrasonic sensors. Tilting the head off the vertical axis produces distance changes that are detected by stationary sensors and translated into motor control signals for an electric wheelchair. Human commands to robotic systems can be performed using these and other schemes.

SUMMARY

The Polaroid sensor system has proven to be an efficient way of obtaining information about the inanimate and human environment surrounding a device. This device could be either a robot or a human/machine interface. In many instances, the distance data acquired is sufficient to control a robot or convey the wishes of a user. The Polaroid technology is commercially available and, by application of the techniques described here, can be integrated into a microcomputer system.

More information about the Polaroid Ultrasonic Ranging system can be obtained from the Polaroid Corporation, Ultrasonic Ranging Marketing, 1 Upland Road, Norwood, MA 02062, telephone (800) 225-1618 or (617) 547-5177. The AM9500 Peripheral Products Interface Guide is available from Advanced Micro Devices, 901 Thompson Place, PO Box 453, Sunnyvale, CA 94086, telephone (408) 732-2400.

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Excellent	Good	Fair

Calendar: *Continued from p. 4*

hibitors are expected to demonstrate the latest in vision technology. The exposition will feature the latest in assembly, inspection, related vision components, computerization technologies, robotics, software, part identification, and sensors. RIA's sponsorship of Vision '85 is an outgrowth of the trade association's new emphasis on machine vision.

27 March. Automated Inspection Seminar. Ontario Robotics Centre, Peterborough, Ontario, Canada. Contact: Susan Harvey, Workshop Registrar, Ontario Robotics Centre, 743 Monaghan Rd., Peterborough, Ontario, Canada K9J 5K2, telephone (705) 876-16ll (Peterborough) or (416) 675-4363 (Toronto).

This seminar is directed toward managers and executives with an entry-level knowledge of today's automated inspection technology. Participants will be introduced to the capabilities and benefits of automated inspection techniques. No previous hands-on work with robots is required.

APRIL

17–24 April. Hanover Fair. Hanover, West Germany. Contact: Delia Associates, PO Box 338, Whitehouse, NJ 08888, telephone (201) 534-9044.

The 1985 Hanover Fair will place special emphasis on mechanical and fluid power transmission, controls, and industrial parts handling. A separate sector of the fair has been set up to accommodate pertinent exhibits.

18–21 April. FutureWorld Expo. Moscone Center, San Francisco, CA. Contact: FutureWorld Expo, 940 Emmett Ave., Suite 14, Belmont, CA 94002, telephone (415) 595-2708.

FutureWorld is a unique marketplace for presenting new ideas, new technologies, new products, and visions of our world to come. Exhibited products include robots, computers, new automobile innovations, and the latest in fashion and home design.

22–25 April. LASERBOTICS: Combining Laser and Robot Technologies. Ann Arbor, MI. Contact: Steve Palma, SME Special Programs Department, One SME Drive, PO Box 930, Dearborn, MI 48121, telephone (313) 271-1500.

The program will feature speakers from the U.S., Europe, and Asia and will examine the latest advancements in the science of combining lasers and robots to improve productivity. Co-chairperson Jack Lane, director of the Robotics Center at the GMI Engineering and Management Institute, and David Belforte, president, Belforte Associates, are preparing an agenda covering the latest advancements in laser tooling, robotic part presentation, laser-guided robotics, fiber optics, laser/robot welding and inspection.

23–24 April. 1985 Conference on Intelligent Systems and Machines. Oakland University, Rochester, MI. Contact: Professor Nan K. Loh, Conference Chairman, Center for Robotics and Advanced Automation, School of Engineering and Computer Science, Oakland University, Rochester, MI 48063.

Papers to be presented at the conference will reflect both advances and applications in all aspects of intelligent systems and machines. Topics will include: intelligent robots, machine intelligence, adaptive control and estimation, visual perception, artificial intelligence for engineering design, intelligent simulation tools, computer-integrated manufacturing systems, knowledge representation, expert systems, game theory and military strategy, interpretation of multisensor information, and automatic programming.

24–26 April. UNIX* Systems Expo/85–Spring. Moscone Center, San Francisco, CA. Contact: David Small, Computer Faire, Inc., 181 Wells Ave., Newton, MA 02159, telephone (617) 965-8350.

This marketing event will address value added resellers, systems integrators, software developers, distributors, dealers, retailers, and OEMs, as well as volume end-user prospects from large corporations, small businesses, government, and education. Multiuser and multitasking systems, networking products, applications software, programming aids, and peripherals will be showcased.

28–30 April. Intelligent Vision Systems. Holiday Inn, Monterey, CA. Contact: Richard D. Murray, Director of Conferences, Institute for Graphic Communication, Inc., 375 Commonwealth Ave., Boston, MA 02115, telephone (617) 267-9425.

This conference is based on the premise that intelligent vision systems have been shown to be a vital part of the factory automation concept, and that they will play an important role in robot guidance and control, enabling robots to perform many more complicated functions than they have to date. The goal of the conference is to contribute to the industrial educational process by addressing both technical and marketing aspects of intelligent vision.

30 April, 1–2 May. Artificial Intelligence and Advanced Computer Technology Conference/Exhibition. Long Beach Convention Center, Long Beach, CA. Contact: Tower Conference Management Company, 331 West Wesley Street, Wheaton, IL 60187, telephone (312) 668-8100.

The direction of AI '85 is commercial, and technical sessions will include such topics as: AI in Office Automation, Natural Language Interfaces, AI in Defense Systems, Computer Vision, and The Legal and Social Implications of Artificial Intelligence.

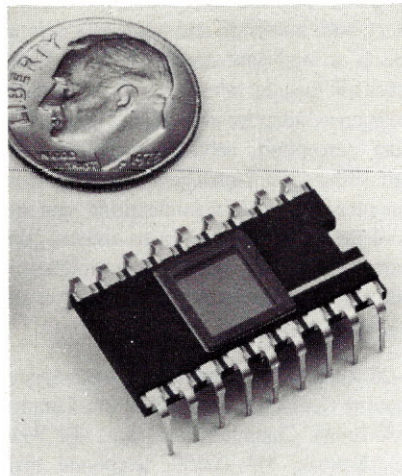
New Products

Silicon Imaging Device

A new charge coupled device (CCD) said to provide low-noise, high-resolution pictures without lag or image burn, and to eliminate blooming and microphonics, has been introduced by RCA. The SID504 measures 0.325 in. by 0.415 in. and contains 512 vertical by 403 horizontal pixels in the frame-transfer design. It is an alternative to camera tubes for many 525-line television applications and is capable of supplying the full resolution of color television.

The CCD's spectral response includes wavelengths extending into the near-infrared spectrum to about 1100 nm; the signal-to-noise ratio is greater than 62 db. The entire image sensing area is light-sensitive and has no opaque areas to cause aliasing, which occurs when small picture details are obscured and lost in the image output. SID504 can handle direct bright lights, eliminating blooming, while at the same time having the high photosensitivity necessary to produce clear images from shadow.

The applications of the new device are expected to be especially significant in low-



light areas where precise image reproduction is required, such as inspection, process control, patten recognition, robotics, and a variety of industrial surveillance, scientific, and medical instruments.

For more information, contact: Robert Fitts, Application Engineering, or George S. Brody, Marketing, RCA New Products Division, New Holland Ave., Lancaster, PA 17604-3140, telephone (717) 295-6998.

Circle 31

RIA Publications Catalog

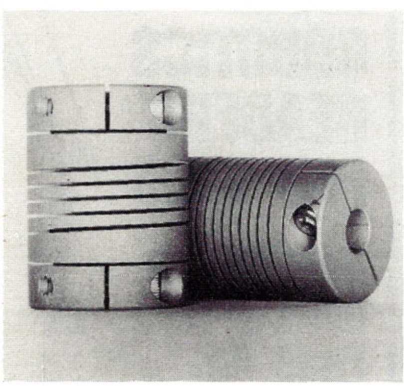
The Robotic Industries Association has published a new, free catalog of current robotics literature. Among titles added since the June 1984 edition are *Machine Vision, RIA Robot Safety Seminar Proceedings and Proposed Robot Safety Standard,* and *14th International Symposium on Industrial Robots Proceedings.*

Machine Vision, published in 1984, is a 388-page softcover directory of over 65 machine vision suppliers. Covered are general vision systems, robotic systems, special systems, vision components and accessories, and optical inspection. Product descriptions are accompanied by photos and drawings. The price is $43 ($40 to RIA members), plus $2 postage and handling.

For more information, contact: Robotic Industries Association, PO Box 1366, Dearborn, MI 48121, telephone (313) 271-7800.

Circle 32

Helical Couplings in Robot Design



Precision manufactured single-piece couplings by Helical Products Company are improving robot arm performance by taking up shaft misalignment and providing low torque positioning when installed in robot optical encoders. The helical couplings are said to be a relatively simple solution to many problems connected with robotics design, for the components are more than simply a way to connect two shafts.

Standard helical couplings are manufactured in diameters from 3/8 to 2¼ in. plus 15, 20, 25, and 30 mm. Inch and/or metric bore sizes may be combined. Aluminum or stainless steel materials and a range of flexure cuts are available. The majority of couplings are custom manufactured to meet specific design criteria of the envelope (outside diameter and length), attachment, material, special end connections, and flexure cuts. Engineering choice of these parameters allows designers to optimize use of the coupling.

Features of the helical couplings include: either direction operation, offset compensation, smooth bearing load, reduction of stress, constant velocity, zero backlash, adaptability to high speeds, and corrosion resistance. They are maintenance free to permit constant precision operation.

For more information, contact: Helical Products Co., 901 West McCoy Lane, PO Box 1069, Santa Maria, CA 93456.

Circle 33

Solid-State Video Camera

A new solid-state video camera with machine vision applications has been introduced by Video Logic Corporation. CDR-460, utilizing the advantages of CCD image devices and external synchronization at RS-170 capability, is a better eye for your computer, the company says. Interlace or noninterlace is possible, and a mechanical shutter and/or high-intensity strobe lights can be added to help capture high-quality pictures of moving objects.

For more information, contact: Video Logic Corp., 597 N. Mathilda Ave., Sunnyvale, CA 94086, telephone (408) 245-8622.

Circle 34

New Products

Low-Noise Electronics

The Eikonix® Corp. has introduced a low-noise electronics board for its Series 78/99, a digital image camera with an optical viewer that uses a linear photodiode array. The board is an amplifier circuit designed to increase the dynamic range and the gray scale discrimination of scanned images. The increased signal-to-noise ratio adds up to two bits per pixel, with an end result of up to ten bits of effective data depth, or 1024 shades of gray. If the data depth required for scanning is eight bits per pixel or less, the low-noise electronics board can increase the scan speed by a factor of two. The board's applications include military, color graphic arts imaging, and x-ray scanning.

For more information, contact: Stephen J. Emery, Eikonix Corp., 23 Crosby Dr., Bedford, MA 01730, telephone (617) 275-5070.

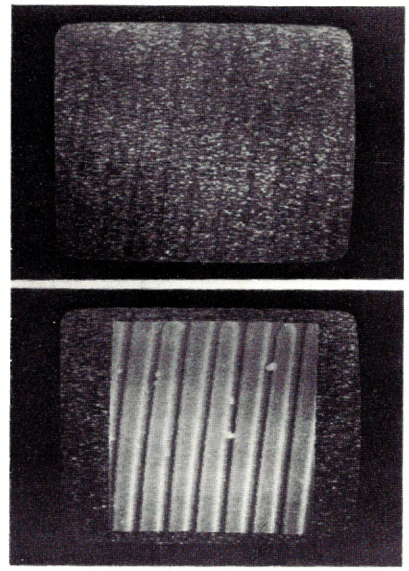
Circle 35

Real-Time Image Enhancement

The TF 5000 from Princeton Electronic Products provides noise reduction as well as image enhancement and manipulation in real time. The device can be used with all standard video and slow scan image sources, allowing viewers to follow a moving image, frame freeze, and enhance spatially static or moving images. It responds to analog or digital inputs in real time and can be coupled to most computers to enhance, manipulate, analyze, and process images under program control.

Input sources may be closed circuit, broadcast or recorded video, infrared or other low-light systems, or medical and scientific research devices such as x-ray and optical fluoroscopes, electron microscopes, ultrasonic scanners, CCD line scanners or even military microwave displays. Outputs can be either television or slow scan.

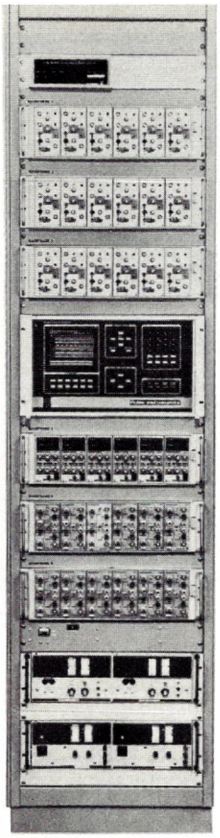
For more information, contact: Sidney Krieger, Princeton Electronic Products, Inc., PO Box 101, North Brunswick, NJ 08902, telephone (201) 297-4448.



Circle 36

New Products

50 MHz CCD Test System



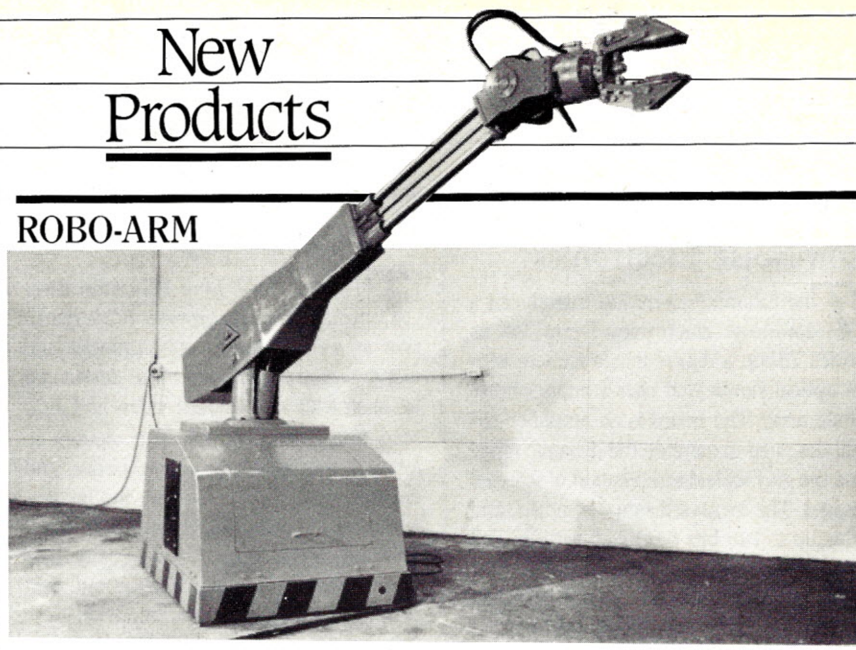
Pulse Instruments has developed the first complete CCD test system to reach the speed of 50 MHz, the company reports. The rack-mounted 9000 Series supplies all necessary operating voltages and excitation signals needed to evaluate every element in a CCD optical array. Low-noise (less than 500 μV peak-to-peak), high-speed performance is achieved through Pulse Instruments' PI-5800 data generator and IEEE 488-compatible voltage source, digital voltmeter, and pulse/CCD driver modules.

The system uses Pulse Instruments modules throughout. Both static and dynamic testing can be done, and the configurations of test modules can be matched to a specific application by using either a single or a dual rack arrangement. An optional scanner is also available for reading driver output amplitude and bias supply voltage.

For more information, contact: Ronald E. Perry, National Sales Manager, Pulse Instruments Co., 1234 Franciso St., Torrance, CA 90502, telephone (213) 515-5330.

Circle 37

ROBO-ARM

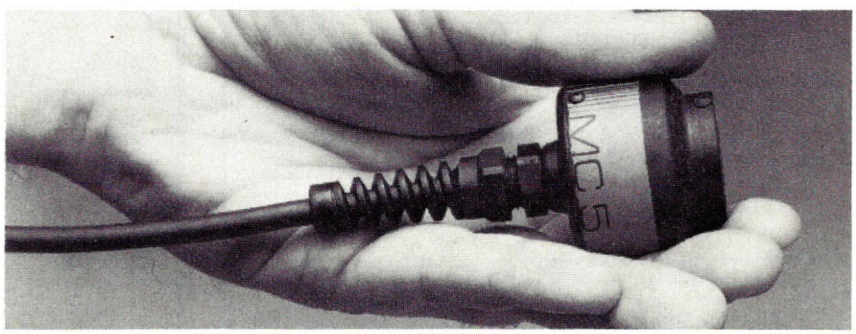


Air Technical Industries has introduced a five-axis modular wrist for industrial use in positioning, loading, offloading, feeding, packing, and assembly functions. Weight capacities range from 100 to 250 lbs., depending on the model. Movement specifications are: wrist rotation 280 degrees, wrist pitch 280 degrees, wrist roll 280 degrees, telescopic arm action, and vertical arm lift 40 degrees up and 20 degrees below horizon. Vertical travel range is from ground level to 12 ft. and horizontal reach is up to 10 ft. All axes are hydraulically operated and require a three-phase, 230/460-volt power source. A variety of grippers and end effectors are available including vacuum, suction cups, and magnets.

The ROBO-ARM can be controlled manually, by automatic sequence, and by computer feedback system, depending on the job requirements. A teach mode control for shop floor programming can be used when walking the robot through the planned sequence of operation which is then recorded in memory.

For more information, contact: Air Technical Industries, 7501 Clover Ave., Mentor, OH 44060, telephone (216) 951-5191.

Circle 38



Immersible Miniature TV Camera

A new lightweight, immersible miniature color television camera that provides high-resolution images in low light has been introduced by MP Video, Inc. The MC-5 camera accurately transmits natural colors under bright and low light, the company says, without image lag, burn-in, or fixed pattern noise. Featuring an image sensor microchip that compensates for varying light levels, the camera provides 3 foot-candle sensitivity and more than 250-line resolution.

The camera weighs 2.5 oz.; the head diameter is 1.5 inches. Automatically calibrating white balance, the EMI and RF shielded camera is connected via a 20 ft. immersible cable to a control unit with color bar generation, LED indicators, and optional character overlaying.

For more information, contact: Peter Wallace, Marketing, MP Video, Inc., 3 Huron Dr., Natick, MA 01760, telephone (617) 655-3311.

Circle 39

Monorail Gantry Robot

Type HBM MOBOT, a half-bridge industrial robot offered by MOBOT Corp., is programmed for any number of "get" and "put" work positions and can be used for part transfer as well as fabricating operations such as drilling and spot welding. Work position coordinates are stored in the internal memory and called for by the system computer in either an abbreviated code or complete command.

An RS-232 interface connects the internal microprocessor and the system computer, and the communication protocol typically is streams of ASCII characters sent in both directions.

All motions are driven by DC servomotors with encoder or resolver feedback. Position, acceleration, deceleration, speed, and stabilization are controlled by the microprocessor and associated standard commercial servo and amplifier boards. All parameters are programmable, and power-off safety brakes are provided on all appropriate motors.

The HBM MOBOT is a modular Cartesian robot, each machine tailored to its particular task by being assembled from a collection of standard motion modules, or Vectrons. The Cartesian mechanism eliminates the need for the trajectory computing required by jointed arm robots, simplifying both hardware and software. The MOBOTs are available in lengths from a few feet up to 200. Lift can vary from one to ten feet and load weights from an ounce to 3000 pounds. Branched configurations are available with up to three grippers or other tools, each on a set of independent axes carried by one or more common axes.

For more information, contact: MOBOT Corp., 980 Buenos Ave., San Diego, CA 92110, telephone (619) 275-4300.

Circle 40

New Vision Systems

GMF Robotics Corp. plans to introduce a true gray scale three-dimensional vision system and a laser-based vision system at the Vision '85 Exposition. The new V-300 gray scale system will perform sealing operations on automotive body parts as a demonstration, directing a GMF-110 robot to follow the auto body seams by compensating for part offsets in all six degrees of freedom.

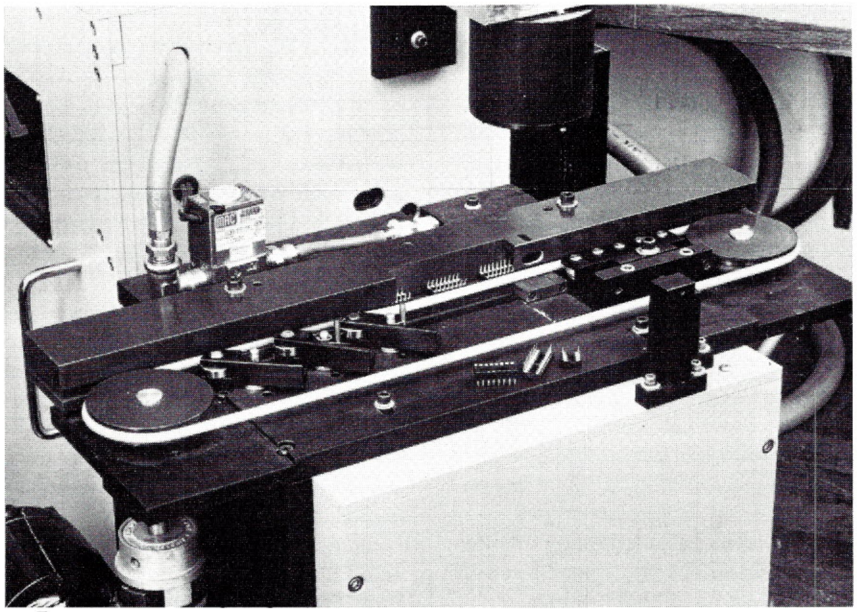
The company will also unveil the Meta-Torch, a laser-based vision system for arc welding applications. Incorporated into a GMF S-110 robotic welding cell, the Meta-Torch will demonstrate its ability to compensate for weld seams on loosely fixtured parts and also provide real-time seam tracking for the welding cell.

For more information, contact: Joan Juzwiak, French & Rogers, Inc., Two Northfield Plaza #303, Troy, MI 48098, telephone (313) 879-2053.

Circle 41

New Products

DIP Socket Inspection System



Automated Systems has developed a high-speed, noncontact method of detecting sprung, crushed, twisted, or missing contacts. Speeds of 500 to 1000 linear inches per minute are possible, depending on line speeds and the type of part being inspected. Inspections are performed on both rows of the socket (top and/or bottom) by either static laser beams or scan lines triangulated off the contacts/pins. Photodetectors receive the reflected light and the signals are digitized by ASI's standard electronic circuitry. The processed data is compared with preset information for verification.

A power feed sends the parts, end to end, into the inspection area. All parameters, including tolerances, are dialed into the system via a keypad with information readout on a plasma display. The system can communicate with other computers and/or printers for trend analysis and statistical information.

For more information, contact: Automation Systems, Inc., 1106 Federal Rd., Brookfield, CT 06804, telephone (203) 775-2581. Circle 42

AI Development Environment

Intellimac has announced a new set of software tools and programs for the development of AI applications on the company's IN/7000 series Ada super-minis. Available for immediate licensing and installation on the IN/7000 systems are:

- Ada-Lisp—An interactive, interpretive Common Lisp development environment written entirely in Ada, complete with programming support tools and Lisp debugger.
- Lisp-to-Ada Translator—A Lisp program that performs fast, automated translation of Lisp source programs to ANSI/MIL-STD 1815A Ada. The output Ada programs can then be compiled for a 7-to-1 increase in execution speed.
- DEXPERT—An Expert System Shell written in Lisp that allows the user to create and query his or her own custom rules-based expert systems in plain English.
- Lisp Tutor—A computer-aided instruction program for the Lisp language, written in Lisp. It allows the user to learn Lisp interactively, at his or her own pace and schedule.

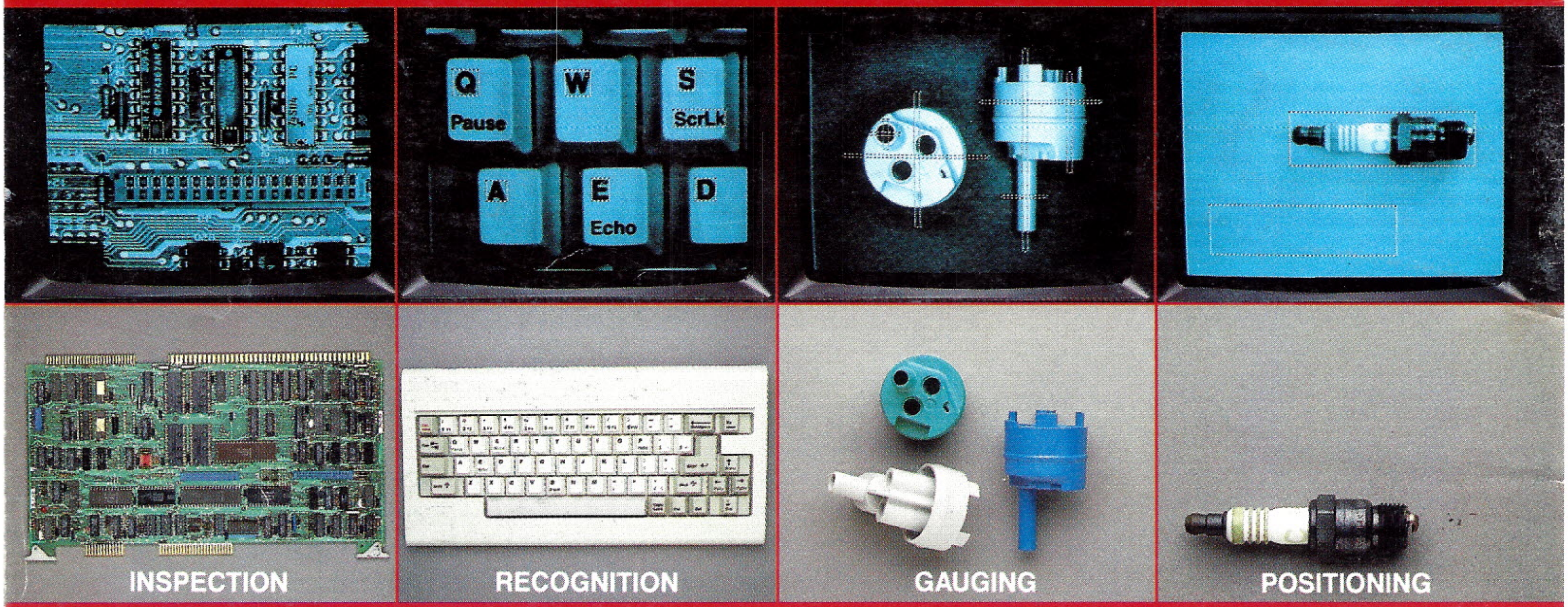
Ada-Lisp and the Translator together allow rapid prototyping of Lisp-based AI functions which can then be converted to Ada packages. The resulting ADA packages, developed functionally in Lisp, can be compiled and linked into a larger Ada program that might perform procedural operations. The Lisp-Ada integrated environment converts the IN/7000 into a cost-effective, multiuser AI development and retargeting system. The IN/7000M supports up to four control processors with up to six users each.

For more information, contact: Bob Huberfeld, President, Intellimac, Inc., 6001 Montrose Rd., Rockville, MD 20852, telephone (301) 984-8000.

Circle 43

Classified Advertising

At last a machine vision instrument with perfect 20/20 vision... Applied in 20 minutes... Responds in 20 milliseconds.



In fact you can apply a single APP 90 machine vision instrument on all of the above example tasks in less than 20 minutes. Then depending on your application have the same APP 90 perform each in 20 milliseconds without subroutine loading or any other overhead delays.

How does the APP 90 perform at this high level?

By hardware not software. The APP 90 does not use a computer running user generated programs. Instead the APP 90 is an adaptive hardware instrument with more application flexibility than software based systems. It operates by converting images into representative values which are labeled and stored in memory. With subsequent appearances of those "trained" images, the APP 90 simply responds to the inquiry with an appropriate output of information.

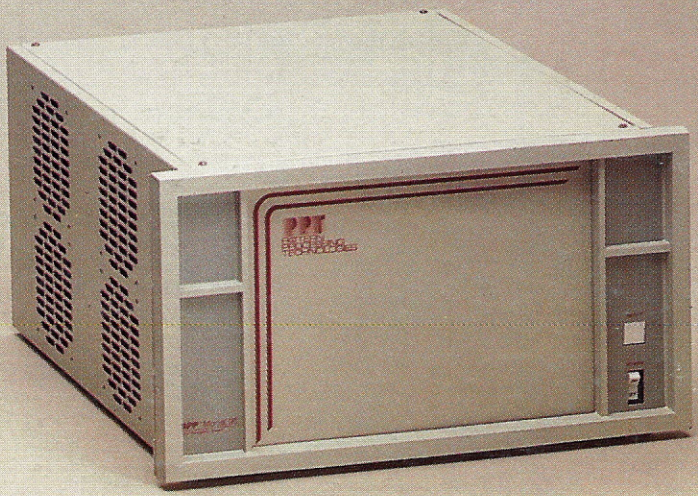
Why an instrument and not a system?

PPT already markets a complete vision system, the APP 200, which includes external control and communication capabilities. But a growing number of users, developing their own CIM systems, only require an "intelligent sensor" device in order to add vision to the system. Our vision instrument will eliminate a redundant processor and programming.

Will the APP technology fit your application?

The only true test of any machine vision product is how it will run your application. We'd like to show you the APP in action. If you are interested send for an applications information form as the first step.

The APP 90



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Circle 17